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Evaluation of existent monitoring hardware for the ultimate purpose of detecting the industrial wastewater source causing chronic or acute inefficiency in the performance of a joint biological treatment facility. The approach represents the first phase of the ultimate purpose; that phase being bench and pilot scale bio-treatment studies of selected industrial wastes at various loadings. Several monitoring techniques were applied to the treatment systems, and the parameters identified in pretreatment guidelines were monitored as measures of removal efficiencies.

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DEVELOPMENT OF A BIOLOGICAL SIMULATION MONITOR FOR JOINT MUNICIPAL/INDUSTRIAL TREATMENT SYSTEMS

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FOREWORD

The Environmental Protection Agency was established to coordinate administration of the major Federal programs designed to protect the quality of our environment.

An important part of the Agency's effort involves the search for information about environmental problems, management techniques and new technologies through which optimum use of the nation's land and water resources can be assured and the threat pollution poses to the welfare of the American people can be minimized.

EPA's Office of Research and Development conducts this search through a nationwide network of research facilities.

As one of these facilities, the Robert S. Kerr Environmental Research Laboratory is responsible for the management of programs to: (a) investigate the nature, transport, fate and management of pollutants in ground water; (b) develop and demonstrate methods for treating wastewaters with soil and other natural systems; (c) develop and demonstrate pollution control technologies for irrigation return flows; (d) develop and demonstrate pollution control technologies for animal production wastes; (e) develop and demonstrate technologies to prevent, control, or abate pollution from the petroleum refining and petrochemical industries; and (f) develop and demonstrate technologies to manage pollution resulting from combinations of industrial wastewaters or industrial/municipal wastewaters.

This report contributes to the knowledge essential if the EPA is to meet the requirements of environmental laws that it establish and enforce pollution control standards which are reasonable, cost effective and provide adequate protection for the American public.

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Director
Robert S. Kerr Environmental Research Laboratory

ABSTRACT

The entry of an accidental slug or shock load from an industrial contributor into a joint municipal wastewater treatment plant (WWTP) can greatly reduce plant efficiency. A Biological Simulation Monitor (BioMonitor) provides a means of continuously monitoring the influent to a WWTP for variations in chemical or physical composition. The microorganisms in the aeration basins are the most vulnerable components of the treatment facility to upsets.

The preliminary studies involved a specifically designed continuous respirometer. The final BioMonitor system is an early warning system based upon the continuous measurement of ambient dissolved oxygen (DO) level in a specially modified laboratory-type activated sludge unit. The feed to the system is the WWTP's influent. Under conditions of constant temperature and pressure, the change in DO reflects oxygen uptake (utilization) by the microorganisms. Changes in utilization in turn reflect changes in substrate or influent constituents.

Laboratory studies employing controlled feed to microorganisms ratios (F/M) and ten industrial wastes have shown the BioMonitor system to produce:

- a rapid response to the introduction of a shock load
- a direct correlation between change in DO (magnitude and direction) and concentration and chemical nature of shock (i.e. wastes of known high BOD, known heavy metals or other toxics, etc.)
- no significant difference in K_La values between baseline and shock feeds.

On-site testing at two WWTP's and a contributing industry at each have corroborated the laboratory results. During field testing the BioMonitor indicated changes in the influent three hours before the flow reaches the bio-population in the aeration basins. A companion BioMonitor system located online at a contributing industrial site monitors the wastewater as it leaves the plant. Problems can be identified and an increase in the warning time (equal to the time of flow on the sewers) can be given to the WWTP.

After the initial period of installation and trouble-shooting, maintenance on site is simple and minimal.

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ABBREVIATIONS AND SYMBOLS

ABBREVIATIONS

A.B. -- aeration basin
ATP -- adenosine triphosphate
BOD -- biochemical oxygen demand
C_L -- oxygen concentration
COD -- chemical oxygen demand
C_S -- saturation concentration of oxygen in water for a given temperature and pressure
DNA -- deoxyribonucleic acid
DO -- dissolved oxygen
F/M -- food concentration to microorganism concentration
$K_L a$ -- oxygen transfer coefficient
MLSS -- mixed liquor suspended solids
MLVSS -- mixed liquor volatile suspended solids
$(NH_4)_2HPO_4$ -- dibasic ammonium phosphate
O_2 -- oxygen
r_r -- microorganism respiration rate
s -- sensitivity
So -- BOD concentration of the feed (substrate)
SS -- suspended solids
t -- detention time
TDS -- total dissolved solids
TF -- triphenyl formazan
TOC -- total organic carbon
TTC -- triphenyl tetrazolium chloride
WWTP(s) -- joint municipal/industrial wastewater treatment plant (s)
X_v -- concentration of biomass (MLVSS)

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SECTION 1

INTRODUCTION

Joint municipal-industrial sewage treatment systems can experience a high loading or toxic discharge from an on-line industry. This can reduce the treatment facility's efficiency or "knock-it-out" entirely. The purpose of the Biological Simulation Monitor is to provide an early warning of these high load or toxic conditions. In some cases the problem flow could then be diverted and/or treated or the treatment facility could modify operating procedures to better accommodate the waste.

A secondary ramification is enforcement - that is, to whom to charge the costs for handling this loading or the cost of reestablishing the biosystem. The enforcement aspect is accomplished by industrial contributors employing a BioMonitor on their plant effluents. More importantly, this arrangement could indicate that a suspected plant is not the one at fault since nothing abnormal was indicated on their monitoring system at the time of the shock loading.

This study focuses on the development and design of the "BioMonitor". This system provides a rapid and reliable means for early warning detection of problematic influent to biological treatment systems.

SECTION 2

CONCLUSIONS

A device that produces a rapid response to changes in influent loadings at wastewater treatment plants has been designed, developed and demonstrated. It is called the "BioMonitor," [Biological Simulation Monitor for a Joint Municipal/Industrial Treatment system (WWTP)]. The device is based upon the measurement of changes in dissolved oxygen (DO). The microorganisms themselves monitor their own "health" using DO as the monitoring parameter. Microorganisms in a small scale activated sludge system utilize the DO in conjunction with influent substrate decomposition. Changes in substrate cause changes in utilization of DO which arereflected by changes in the ambient level of DO monitored.

The system is useful for industries which treat their own wastewater as well as for WWTP facilities. By locating a BioMonitor at an industry contributing wastewater to a WWTP, advance warning of a "problem" load can be given; said warning equal to the time of flow in the sewers. Test results from a BioMonitor located within WWTPs indicate that an approximate three hour warning can be given before the problem flow reaches the microorganisms in the plant's aeration basins.

An increase in DO can reflect a toxic or inhibitory loading or a decrease in substrate (BOD). A decrease in DO reflects an increase in substrate (BOD) loading. The DO readings include inherent variations due to changes in temperature. After the direction of the DO change is established, tests must be run to determine the specific cause of the DO change. The potential exists for the use of the BioMonitor as a controller to divert and/or treat problem influents as warranted by the specific nature of the problem.

The BioMonitor can be employed as an enforcement tool. If a WWTP's treatment efficiency werereduced because of problem industrial wastes, major contributing industries could be called upon to produce the strip chart recordings of their BioMonitor's response for the period in question. The presence or absence of anomalous behavior could help ascribe responsibility for the WWTP upset. Changes could be made accordingly.

SECTION 3

RECOMMENDATIONS

1) It is recommended that additional investigations be performed to correlate effluent quality with influent changes and BioMonitor response. The procedure would be analogous to that employed in the design and development of the BioMonitor system itself. Specifically, it is recommended that the investigation framework and preliminary studies be performed in the laboratory. On-site studies would then follow.

2) It is recommended that the BioMonitor be tested at additional joint industrial wastewater treatment plants (WWTP). It would be beneficial for these WWTPs to have a history of plant upsets due to industrial contributors.

3) It is recommended in conjunction with recommendation (2) above that the application of the BioMonitor in determining the industrial source(s) of a shock load to a WWTP be demonstrated.

4) It is recommended that the BioMonitor be tested at industrial plants which treat their own wastewater. It is recommended, where applicable, that companion BioMonitors be positioned at the major discharge points as well as at the confluence point. The former could help locate the source of the systemic shock within the industrial plant. The latter could detect synergistic effects on the microorganisms from the combined waste streams.

5) It is recommended that the potential use of the BioMonitor as a controller be investigated. This is based upon the fact that the response of the BioMonitor to input changes is much more rapid than the response of the biological treatment plant system. In conjunction with the investigations recommended in (1) above, the dynamic response of the BioMonitor to input changes must be characterized and subsequent application to control schemes (i.e., feed forward control) should be explored.

6) It is recommended that the mathematical model of BioMonitor response be verified both in the laboratory and, if successful, on site.

7) It is recommended that additional instrumentation work be performed on the dissolved oxygen (DO) meter and/or recorder. Studies should be performed to determine the benefits of monitoring a differential response versus ambient DO readings. It is recommended that the DO monitoring electronics be altered to automatically remove temperature effects. An alternative way of eliminating temperature effects is to control the temperature of the unit at 20°C by a thermostating process. This alternative could result in a different microorganism efficiency in the BioMonitor from that existing in

the WWTP's aeration basin. It is recommended that the two alternatives be studied and complete evaluations performed prior to selection of the means of compensating for physical temperature variations in DO levels.

8) Finally, it is recommended that additional steps be taken so that the BioMonitor system could be packaged in unitized (modular) form for use at biological wastewater treatment facilities.

SECTION 4

STATE-OF-THE-ART REVIEW

The BioMonitor is a device to detect variations in the composition of the influent to a joint municipal/industrial wastewater treatment plant (WWTP). If the variation of the influent is caused by a toxic discharge or an unusually high BOD loading, the facility could be incapable of sufficiently treating the wastestream. This reduced efficiency would result in poor effluent quality and/or the need to regenerate the system (replace the biomass in the aeration basins). If the latter effect is experienced, poor quality effluents will be discharged for approximately one to two weeks.

The BioMonitor, which is a modified laboratory scale activated sludge system, continuously samples the influent to the WWTP. The BioMonitor responds to changes in influent loading prior to the impact of these changes on the microorganisms in the aeration basins. By the judicious placement of the BioMonitor system at the WWTP during field testing, an average three hour period exists before the problem flow reaches the biopopulation in the large aeration basins. By positioning companion BioMonitors on the effluents of the major industrial contributors to the WWTP, additional time can be afforded for the necessary preparations to accommodate the shock load. Secondly, use of the companion BioMonitors affords an enforcement tool - helping to locate the source of an accidental slug. The BioMonitor is also applicable for monitoring the influent variations at an industrial treatment site. The great potential, at either type of facility, lies in its use as a controller to divert flow, adjust pH, etc.

As implied, the microorganism population used in biological treatment at a WWTP constitutes the most vulnerable phase of the facility. The disruptive effects of industrial discharges on biological treatment systems are well known and well documented in literature concerning wastewater treatment. Green (1) mentions a 50 percent mortality rate, occurring within 48 hours, of the enchytracid worm Lumbricillus rivalis due to sewage containing an industrial chemical effluent. Such a reduction in the microorganism populations of a trickling filter can lead to excessive accumulation of microbial film, ponding, and deterioration of the effluent. In the activated sludge process a reduction in effluent quality may be caused by heavy metal ions affecting flocculation and sedimentation. As discussed by Patterson (2), heavy metals such as copper, chromium, nickel, and mercury directly affect the activities of cellular enzymes. Other inhibitors can alter cell membrane permeability, and heat or toxicants such as chlorine may have a general systemic effect destroying cellular integrity. Jackson (3) and Green (1) emphasize the susceptibility of methanogenic bacteria found in anaerobic digestors to poisoning by toxic substances, especially heavy metals, phenols, and chlorinated hydrocarbons. Because of this susceptibility, a test for the presence of toxic materials, using actively digesting sludge and measuring methane gas production, is described (3).

Although continuous monitoring for toxic substances is not common practice at most biological treatment plants, such information is desirable for protection and efficient maintenance of the system. Some gross indications of industrial discharges are significant changes in color, odor, and temperature of the plant influent. Problems such as pump failure and pipe corrosion may result (4). More sensitive and reliable indicators are needed. Below is a brief review of various toxics monitoring systems. These systems fail to meet one or more of the following criteria: continuous monitoring; low cost; high sensitivity; low maintenance; reproducible, rapid and reliable response; and applicability to sewage treatment facilities.

(a) Cairns et al. (5) report on the design of a continuous flow biological early warning system for industrial use. This system involves the use of fish in aquaria (1 per tank). Breathing signs were picked up by electrodes at the ends of the aquaria and recorded by a polygraph. Light beams traversed the aquaria at 3 levels. Counters tabulated the number of time a fish swan through the beam. This count reflected fish activity. The system required highly trained personnel to interpret the polygraph data. Minimum reported lag time between toxicant addition and detection was from 1 to 9 hours. This time span reflected the time requirements for human data analysis. Addition of an analog-to-digital converter, minicomputer and teleprinter would reduce both operator training requirements and time for detection.

(b) Polymetron (6) has marketed the "Condimat" system for the continuous monitoring of toxic effluents in wastewater. The system measures low concentrations of toxic ions such as fluoride, cyanide, sulfide, nickel and chromate using ion specific probes.

Several continuous and semicontinuous monitors based on oxygen uptake rates have been developed. They are described below essentially in chronological order.

(c) Sletten (7) proposed a respirometric (Warburg) screening test for toxic substances in a 3-hour run instead of using fish bioassay. The screening employs a manometric assay of fish tissue (homogenates of brain, heart, gill, and liver, with liver preferred) respiration.

(d) A self-contained sampling and measurement system featuring a continuous respirometer is reported in the literature (8). A sample from the aeration basin or primary clarifier is aerated and continuously metered through an internal residence chamber at a constant rate. DO sensors located at both ends of the chamber sense the differential in oxygen utilized (9). From the available information it appears that this system employs the microorganism populations present in the waters being tested. Such a design appears to reduce its applicability for monitoring industrial plant effluents miles upstream from the WWTP under investigation where the ambient microorganism population would be low. This would result in low utilization and small changes in the DO level.

(e) Another monitor maintains a solution of microorganisms, a sample of which is mixed with the test solution and specific nutrients (10). The mixture is then monitored for a specific parameter such as pH, turbidity, CO_2, or oxygen concentration, with oxygen concentration being the most suitable for toxicity determinations. An inhibition of microbial activity will result in a decrease in the oxygen uptake rate and a subsequent increase in the DO level. The one major drawback to this system is the requirement of a specific monoculture of bacteria in order to avoid mixed microbial responses. Obviously, this would not be applicable to the variable population which comprises activated sludge.

(f) The biological inhibitor detector (BID) has been developed as a sensing device for toxic loads to activated sludge processes (11). The continual monitoring cycle measures and compares the oxygen uptake rates on two propylene glycol samples, one before and one after the exposure of the activated sludge sample to the plant effluent. Any inhibition of the sludge will be reflected in the second oxygen uptake curve, and by comparison to the first, changes in sludge sensitivity can be detected. Each measurement cycle requires approximately 60 minutes to establish such a comparison. The area under the oxygen uptake curve, the total oxygen consumed, was found to be more sensitive and reproducible than the oxygen uptake rate and was used as the monitoring parameter. Continuous and batch toxicity tests show this monitor is responsive to inhibitory effects of heavy metal ions and toxic organic compounds. The system was developed as a part of a more involved, computer controlled, automated optimization of a petrochemical biooxidation wastewater treatment facility.

(g) Arthur (12) presented an on-line instrument for wastewater measurement and control using a manometric respirometer. The system is batch-wise continuous with variable retention times. A portion of a continuously pumped sample is diverted to an aeration column. The system is then sealed and the oxygen consumption measured. The sample is then discharged; column flushed and new sample introduced. The whole system is contained in a temperature controlled water bath.

From the above review and additional investigations into recent laboratory research employing continuous instrumentation (e.g., 7, 13, 14) it was concluded that no existing system could fully meet the requirements of the Biological Simulation Monitor we propose. In each instance some problem in the theory, design or economics precluded the system's use as the "BioMonitor." Consequently, it was decided to review the parameters available for monitoring a joint municipal/industrial WWTP's influent and design the BioMonitor accordingly. The next section is a discussion of this review including the conclusions drawn about the suitability of each parameter for continuous monitoring.

SECTION 5

EVALUATION AND SELECTION OF PARAMETERS FOR USE IN THE BIOMONITOR

The purpose of the BioMonitor is to warn of any changes in influent substrate which could result in an unsatisfactory treatment plant effluent. The major impact of a shock load is on the biomass in the aeration basins. Consequently, a reliable parameter must be a function of microorganism metabolic activity which in turn reflects the rate of substrate removal. Two additional criteria are important in the selection of a parameter on which to base the BioMonitor. Specifically, these are: (a) a sensitive and rapid response; and (b) a relatively easy analysis adaptable for continuously monitoring.

In consideration of the above requirements, nine parameters were selected to be investigated for their potential use in the BioMonitor. (See Table 1 for a list of these parameters). In each case a literature review was sufficient to determine the suitability of the parameter for our needs. Some of the nine parameters were later studied in the laboratory to corroborate the findings of the parameter of choice. (See Sections 6 and 7). The problems encountered in these studies agreed with those predicted from the literature review. The conclusions of the literature review are summarized below.

(a) MLVSS - Mixed liquor volatile suspended solids (MLVSS) is a standard parameter used in biological system control (15). This is a gravimetric analysis. Therefore, the results include living and dead cells as well as inert organic matter. Coackley (16) and Patterson (2) have observed toxic wastes which seriously affected the oxidative capacity of the activated sludge biopopulation but had no immediate effect upon the MLVSS value. Therefore, the use of MLVSS as the monitoring parameter was rejected.

(b) Cell Count - The most direct measurement of viable biomass would be an actual count of living cells. While this is a sensitive method for pure microbial cultures, this procedure cannot be applied directly to activated sludge because of its heterogeneous nature. A medium capable of supporting the growth of numerous species of bacteria, viruses, etc., must be used. However, it is known that the use of one growth medium causes selection. Moreover, it is difficult to separate individual cells. Also, the sample must be homogenized. This step has produced significant increase in the bacterial count (17). These facts plus the inherent time delay in carrying out the counting procedure reduce the usefulness of this parameter for our purposes.

(c) Cell Constituent Measurements - The cells of the microorganisms

TABLE 1. PARAMETERS INVESTIGATED

MLVSS
Cell Count
Cell Constituent Measurement (i.e., DNA, Organic Nitrogen, etc.)
BOD
COD
TOC
ATP
TTC
DO/Oxygen Uptake

in activated sludge contain many constituents for which analytical techniques have been developed. Examples of measurable cell constituents include organic nitrogen, protein and DNA. However, it has been demonstrated that these components are partially retained by the nonviable organisms (2,17,18). The slow responses of these parameters to large and/or rapid changes in biological activity makes them poor choices for an instantaneous performance monitor.

(d) BOD - An indirect measurement of the changes in metabolic activity in activated sludge can be seen by the variations in the Biochemical Oxygen Demand (BOD) of a substrate. The most obvious difficulty in using this parameter is the accepted 5-day test period (19). Moreover, the reported accuracy of BOD analyses is ± 20 percent (20).

(e) COD - Although use of the Chemical Oxygen Demand test (COD) eliminates some of the disadvantages of BOD, the COD variations might not be directly related to the variations in the biodegradable fraction of a waste (15). For this reason, COD was determined to be an inappropriate parameter for the monitoring of sludge activity.

(f) TOC - Analysis for Total Organic Carbon (TOC) can be an automated and continuous procedure, if desired (21). It is frequently employed to monitor a waste stream and the effluent of a treatment plant. However, the analysis does not provide differentiation between living and inert matter. Moreover, the results could not indicate the possible toxic nature of an influent variation or variations in nonorganic components. Consequently, for our purposes TOC is not a suitable monitoring parameter.

(g) ATP - Cellular biochemistry offers several possible parameters to monitor biomass activity. Adenosine triphosphate (ATP) is one such possibility. ATP is a high energy compound found in every living cell.. It is an essential ingredient in the initial biochemical steps of substrate utilization and cell synthesis, and is therefore a specific indicator of cell activity. ATP is not conserved by nonviable cells.

In the analysis, ATP reacts with luciferin/luciferase enzyme, extracted from firefly lanterns. A complex is formed which then reacts with oxygen, forming an excited state followed by light emission (2). The light emission is affected by several factors. The analytical procedure is quite specific with regard to temperature, pH, quality of firefly extract and other reagents, and presence of enzyme inhibitors. Another major drawback for this analysis is the high cost of reagents and equipment (16).

Many studies have been conducted on the applicability of ATP as an activity parameter (2,17,22-26). These studies indicate that the reaction is very susceptible to complications which could result in erroneous interpretation of the data. This problem was borne out in our laboratory analysis. Subsequently, the use of ATP for the monitoring parameter is not the optimum choice.

(h) TTC - Another indicator of the cellular biochemistry of the microorganisms is dehydrogenase activity. During the biological treatment of organic wastes, the dehydrogenase enzymes catalyze the oxidation of the substrate by removing hydrogen ions from it (16,27,28). The normal terminal electron acceptor is oxygen, but the dehydrogenase activity can be measured by providing an artificial hydrogen acceptor. One such electron acceptor is triphenyl tetrazolium chloride (TTC) which, upon reduction, forms triphenyl formazan (TF), a red insoluble dye (see Figure 1). The dehydrogenase activity is measured by determining colorimetrically the amount of TF produced. As in the determination of ATP, the dehydrogenase activity test is quite dependent upon procedural conditions. Variables such as pH, incubation temperature, and reaction time have been studied, and general operating ranges have been standardized (29-32). There is continuing reassessment, however, of such conditions as the use of an organic substrate, means of extraction of TF, and the exclusion of oxygen during incubation. Several procedures have been proposed and used, and conflicting results have been obtained (30, 31). It is generally recognized that dehydrogenase activity responds quickly to changes in both substrate loading and toxic materials, although Jones questions its accuracy as a measure of total biological activity (32). Under aerobic conditions, molecular oxygen acts as an inhibitor and competes with TTC as the terminal hydrogen acceptor.

Several studies have shown inhibition of dehydrogenase activity by heavy metals and pesticides (16,23,30,33). Results indicate a significant and rapid adverse effect on biological activity and a sensitivity comparable to that of a Warburg respirometer (30). The measurement of dehydrogenase activity is considered to have potential for activity studies even though it has procedural complications.

At the present time, there is no automated analytical procedure suitable for the determination of dehydrogenase activity in the heterogeneous biomass of activated sludge. Manual experiments at our laboratory were exacting but did result in reproducible patterns of changes in TTC level which correlated with substrate changes after an appropriate time delay factor. In full consideration of the above, it was decided that at this stage of instrumental development TTC analysis is not a good choice for a continuous monitor of sludge activity.

(i) DO/Oxygen Uptake - The change in the level of dissolved oxygen (DO) is a good indicator of the activity of a biological system. The endogenous and exogenous respiration of the microorganism contributes to oxygen utilization. Endogenous microbial respiration uses oxygen for the degradation of internally stored (intracellular) substrate reserves. Exogenous microbial respiration uses oxygen to degrade the substrates in the influent waste. Exogenous demand changes much more rapidly with influent variations than endogenous. Moreover, the effects of changes in certain parameters, e.g., temperature or pressure, upon DO level is understood and predictable.

The measurement is both automated and continuous when using a galvanic cell DO analyzer. The development of this membrane electrode probe has made possible near instantaneous DO readings with a precision of ± 0.1 mg/l (34-36). Laboratory tests have been conducted to determine whether a DO probe responds quickly enough to changes in DO concentration to yield accurate oxygen uptake rate measurements (35). The meter response was shown to be

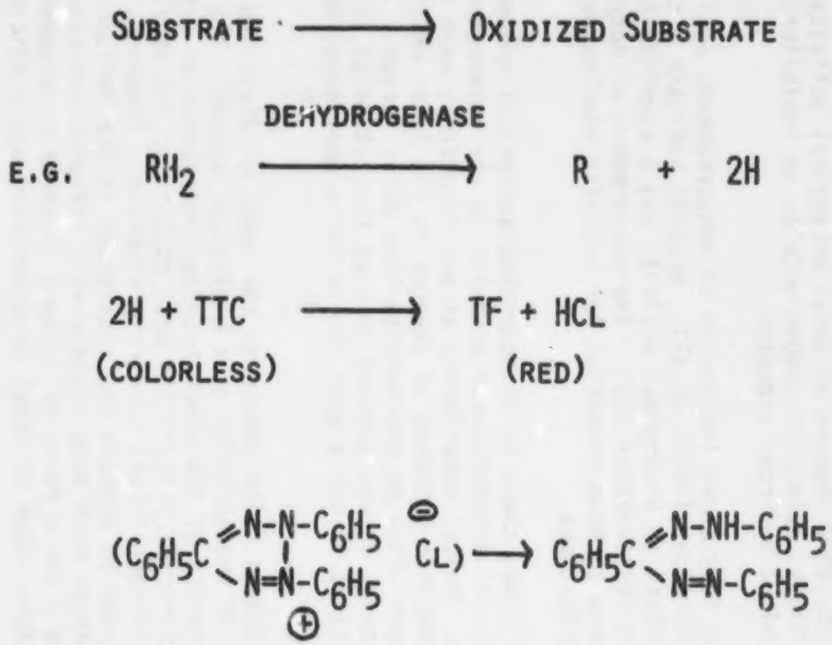

SUBSTRATE → OXIDIZED SUBSTRATE
DEHYDROGENASE
E.G. RH2 → R + 2H
2H + TTC → TF + HCL
(COLORLESS)
(RED)
(C6H5C=N-N-C6H5 / N=N-C6H5 + CL−) → C6H5C=N-NH-C6H5 / N=N-C6H5

Figure 1. TTC reaction.

adequate for oxygen uptake determinations up to 300 mg/l-hr, which are far above those normally encountered. The instrumentation is comparatively inexpensive with minimal maintenance.

Oxygen (O_2) uptake is a measure of the change in DO level caused by microorganism utilization. Oxygen uptake can be measured by a respirometer with or without membrane DO probes. The measurement of oxygen uptake (rate) reported in mg/l per hour, has been undertaken in many studies to determine the effect of toxicants and inhibitors on activated sludge (1,2,13,17,23,26, 33,37,38). In almost all cases, the oxygen uptake rate has shown rapid response, and, in one particular study, showed significantly more inhibition than the ATP or dehydrogenase activity measurements. The measurement is simple (using oxygen electrodes), sensitive, and rapid.

The most common respirometer is the Warburg. Basically a respirometer operates as follows (see Figure 2 for a general schematic): a sealed sample container holds both the microorganisms and the sample in question. Connected into the container is a means of measuring the decrease in the partial pressure of oxygen in the closed atmosphere above the sample. This decrease is usually measured manometrically. The two main drawbacks to the Warburg respirometer are the small size of samples studied and the inefficient absorption of the carbon dioxide (CO_2) produced as a result of oxidation (16). Developments have been made, however, on large volume respirometers which provide more detailed information on respiratory activity. Arthur (39) has developed an automatic respirometer which recycles both air and liquid countercurrently through a large, closed reaction chamber. Carbon dioxide is absorbed by sodium hydroxide. Research has shown that this respirometer can approximate the 5-day BOD in a period of 4 hours (20). Another large volume respirometer has been developed to yield BOD data and treatment plant design parameters within 24 hours (40).

Robertshaw Controls Company has developed an automatic respirometer which uses two DO probes, one at each end of a residence chamber. These probes measure the differential in oxygen utilized by activated sludge throughout the system (41). The data is reported as oxygen uptake, in milligrams per liter per hour, and the response time is approximately two minutes. Other similar respirometers using membrane electrode probes have been developed with response times of 4 to 18 hours. Measurement of changes in DO level as an indication of oxygen uptake using a membrane probe is very simple.

The relationship between oxygen uptake rate, DO level and oxygen transfer is mathematically described as follows (42):

$$dC_L/dt = K_La\ (C_s - C_L) - r_r \qquad (1)$$

where:

dC_L/dt is the change of oxygen concentration in the activated sludge unit with respect to time

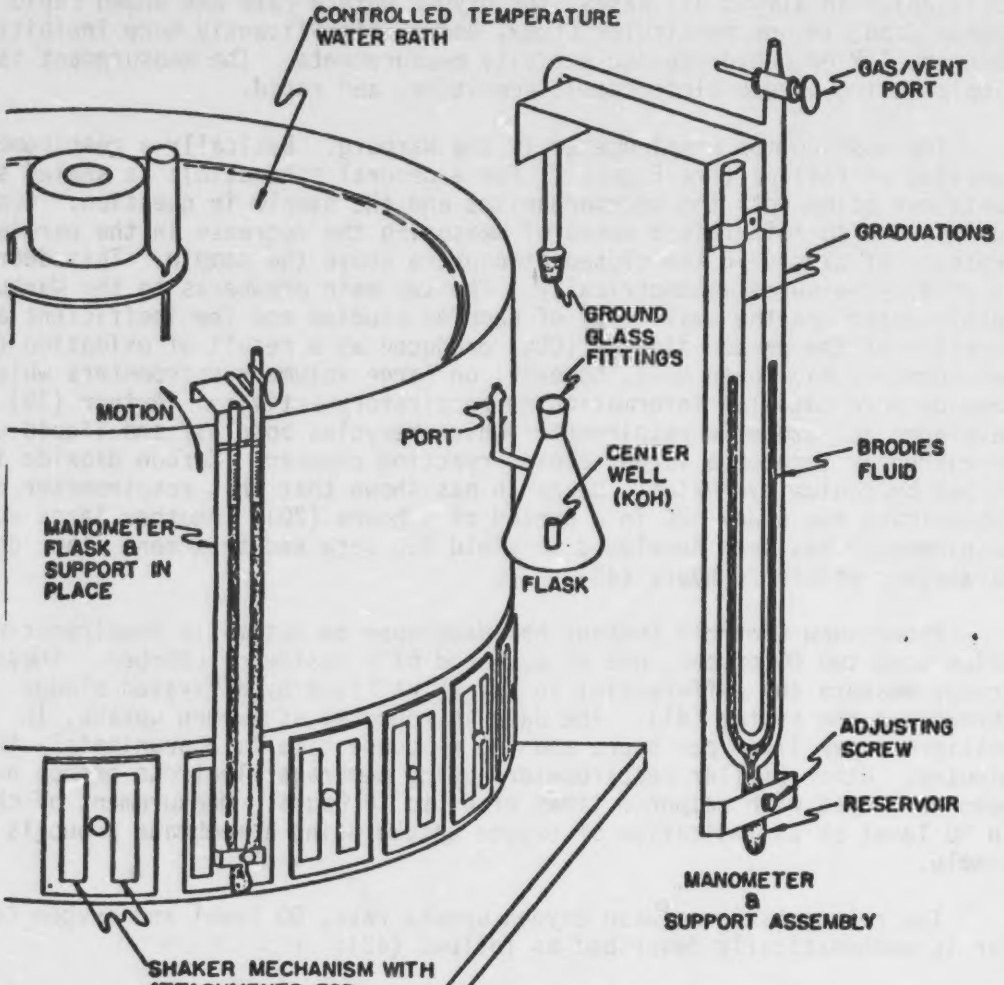

CONTROLLED TEMPERATURE WATER BATH
GAS/VENT PORT
GRADUATIONS
GROUND GLASS FITTINGS
MOTION
PORT
CENTER WELL (KOH)
BRODIES FLUID
MANOMETER FLASK & SUPPORT IN PLACE
FLASK
ADJUSTING SCREW
RESERVOIR
MANOMETER & SUPPORT ASSEMBLY
SHAKER MECHANISM WITH ATTACHMENTS FOR MANOMETER SUPPORTS

Figure 2. Schematic of a Warburg Respirometer.

K_La is the oxygen transfer coefficient in the activated sludge unit

C_s is the saturation concentration of oxygen in water for a given temperature and pressure (constant during period of K_La run)

C_L is the oxygen concentration in the system

r_r is the biological respiration rate (oxygen uptake by organisms - constant during period of K_La run).

Under unsteady state conditions, where the DO level is changing with time ($dC/dt \neq 0$), the change in oxygen levels can be attributed to a change in the oxygen uptake rate (biological activity) only if the oxygen transfer coefficient, K_La, remains constant. For this reason, a system using the oxygen uptake rate as the monitoring parameter should maintain constant oxygen transfer during the period of interest. This transfer is a function of the level of air flow and the aerator efficiency. Since the air flow can be measured by a rotameter, K_La is evaluated according to the type of aeration device used.

Albertson and DiGregorio (35) have concluded from bench scale studies and actual treatment plant performance data that oxygen uptake rates can affect the overall oxygen transfer. This relationship between mixed liquor oxygen uptake rate and the oxygen transfer capacity is explained by the direct transfer of oxygen from air bubbles present in the mixed liquor to the microorganisms. Other bench scale studies were performed to determine if there were an oxygen demand accumulation at low DO levels. No inhibition of oxygen uptake rate, as shown by an oxygen demand accumulation, occurred even at DO levels as low as 0.1 mg/l. Only when there was continued substrate feeding and no aeration at all, did any oxygen demand accumulation result.

Other studies on inhibition of oxygen uptake rate have shown similar results. Weddle and Jenkins (17) report that DO uptake rates of activated sludge are not affected by the DO concentration unless it falls below 0.5 mg/l. They do mention an effect on the rate of oxygen uptake due to the turbulence to which sludge flocs are subjected. Gaudy and Turner (38) also studied the effects of low oxygen tension and their results indicate that only DO levels below 0.5 mg/l alter respiration rates. Their work revealed that a short term absence of DO will not seriously affect the substrate removal rate. Other basic microbial studies have shown that the concentration of DO over a range from 0.5 to 35 mg/l does not affect the respiration rate of dispersed cells (43). It can thus be concluded that the normal DO levels found in properly operated activated sludge treatment systems and the modified bench scale unit under study will not affect the rate of oxygen uptake. Duggan and Cleasby (44) conclude that "there is a direct response in mixed liquor DO to influent substrate load variations when DO levels are above the concentration critical to microbial oxygen utilization."

After careful consideration of the information gathered about the nine parameters under investigation, the parameter selected for use in the Bio-Monitor is DO/oxygen uptake rate. The continuous measurement of ambient DO level using a membrane probe best meets the criteria discussed earlier. The change in DO level (oxygen uptake) is a function of the oxygen utilization of the microorganisms which in turn reflects the substrate removal. Moreover, the analysis is rapid, simple and continuous. The equipment cost is comparatively low as are the maintenance requirements.

The next step was the development of a preliminary BioMonitor for laboratory investigations. This is essentially a continuous oxygen uptake monitor using membrane probes (or respirometer as described earlier) designed to meet our specific needs. The development of this unit and the results and conclusions drawn from various testing procedures are discussed in Appendix A. In the next section, the details of the design, development and testing of the BioMonitor system are presented.

SECTION 6

DEVELOPMENT OF THE BIOMONITOR

DESIGN OF THE BIOMONITOR

Figure 3 is a schematic of the cylindrical BioMonitor. Figure 4 is a photograph of the system. The significant feature of the BioMonitor is the introduction of the feed directly into the contact chamber. Unlike the side car of the previous unit, the contact chamber is not air tight. Rather, it has a constant air flow entering at the bottom. This air stream provides a source of dissolved oxygen for the chamber, acts as an air lift pump; and mixes the contents of the chamber. The air lift continuously returns the chamber's contents to the aeration basin. A return tube is continuously adding mixed liquor from the aeration basin to the contact chamber. The contact chamber holds a maximum of 5% of the total BioMonitor's volume. The clarifier has an approximate volume of 2,200 ml and the aeration basin approximately 6,900 ml. A representative contact chamber volume is 400 ml. Consequently, if the feed is sufficiently toxic to kill the microorganism on contact, the aeration basin acts as a source of viable organisms. Although this source is becoming contaminated by the nonviable organisms, this design allows a continuing readout from the contact chamber to warn of the toxic shock load. Moreover, by providing a reservoir of biomass, the BioMonitor can be employed at a contributing industry miles away from the WWTP. This remote system not only helps locate the source of a problem discharge but also increases the warning time.

A DO probe measures the change in dissolved oxygen in the chamber. The probe is inserted horizontally, approximately midlength in the contact chamber. At first the protective shield was removed from the probe and the probe was inserted into a threaded port. This proved unsatisfactory. Turbulence in flow often disturbed the membrane fit. Also the seal frequently proved not to be water tight. This design was replaced by a collar and clamp combination which not only allowed the probe shield to be kept in place but also reinforced the portal against splitting. Teflon tape was wrapped around the probe before insertion to eliminate any leaks.

A constant DO level can be maintained for a given set of variables (MLVSS, air flow, feed flow, temperature, etc.). The data supporting this statement are given later on in this section. More importantly, the data indicated that during the period of a shock (approximately 15 minutes) the K_La varies only an average ± 5%. Consequently the DO is not significantly affected by changes in oxygen mass transfer rates during the test period. Therefore the changes in DO reflect the changes in microorganism respiration

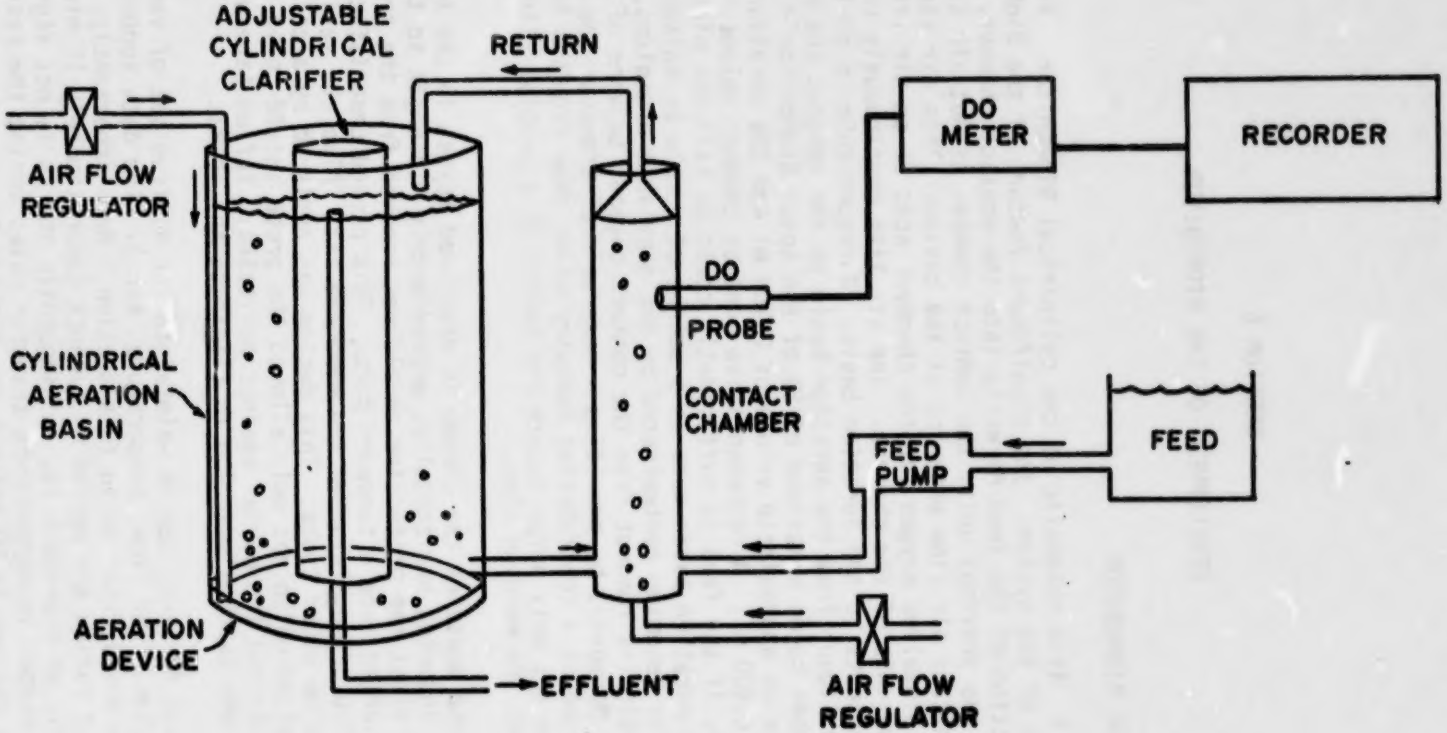

ADJUSTABLE CYLINDRICAL CLARIFIER
RETURN
AIR FLOW REGULATOR
DO METER
RECORDER
DO PROBE
CYLINDRICAL AERATION BASIN
CONTACT CHAMBER
FEED
FEED PUMP
AERATION DEVICE
EFFLUENT
AIR FLOW REGULATOR

Figure 3. Schematic of cylindrical BioMonitor.

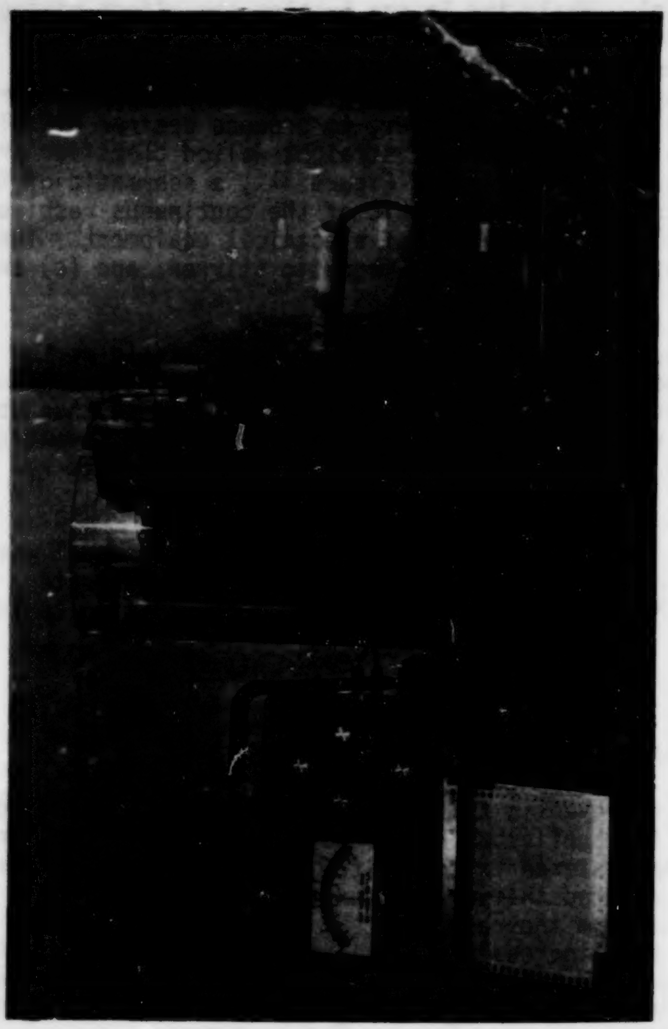


Figure 4. Photograph of the cylindrical BioMonitor

as a response to changes in substrate for a given set of BioMonitor conditions.

The retention time in the contact chamber can be varied by (a) changing the volume of the chamber; (b) changing the feed flow rate; or (c) changing the air flow rate.

The cylindrical design for the aeration basin was chosen in an effort to effect mixing without mechanical stirrers. A circular aeration device with holes larger than those of the bubble wand is employed. (See Appendix A for description of sparger). While the larger bubbles can effect mixing, their oxygen transfer is less efficient. However, since the measurements of interest are made in the contact chamber which is supplied with its own air source, efficiency of oxygen transfer is not vital. Air flow can be regulated, independently from the contact chamber, to produce desired dissolved oxygen levels and mixing. The cylindrical straight-walled clarifier produces high quality effluent. A comparison of Figure 3 , a schematic of the BioMonitor system with Figure A-1 , the schematic of the continuous respirometer, shows the elimination of three pieces of electrical equipment. These include: (a) a solution metering pump; (b) a magnetic stirrer; and (c) an electrical mixer.

The elimination of electrical equipment produced a more field worthy instrument. It was proposed that the direct introduction of the feed into the contact chamber would produce a larger and more rapid response than obtained from the continuous respirometer. These suppositions were investigated in a series of laboratory experiments. The investigation and its results are discussed below.

Appendix B contains a dynamic model of the BioMonitor. The model was developed as a function of oxygen uptake, volatile solids and substrate concentrations in the aeration basin and contact chamber in relation to influent characteristics.

LABORATORY INVESTIGATIONS

Characterization of the BioMonitor

The testing procedure employed in this study was similar to that used in the characterization of the continuous respirometer. Specifically, controlled shock loads were administered to the unit. The shocks were prepared by varying the amounts of powdered skim milk added to the baseline feed. In consideration of the results from the respirometer, the baseline feed was at an F/M = 0.23. This level gave increased sensitivity (greater changes in DO) of response over systems run at a baseline F/M = 0.3. It also enabled the solids level to be maintained. Unless otherwide indicated, all subsequent variations will be compared to a baseline feed of F/M = 0.23.

A first order of business was an intersystem comparison to ascertain what if any increased response was obtainable from the new design. The assumptions were upheld. The new configuration resulted in both increased sensitivity and rapidity of response. The results are seen in Table 2.

The BioMonitor in this case was run at an F/M = 0.3 (or 0.4) so that significant comparisons could be made.

TABLE 2. INTERSYSTEM COMPARISON (CHANGES IN DO)

ΔF/M units	ΔDO, mg/l		
	Continuous Respirometer*	Cylindrical Unit	
		Prototype**	Plexiglas***
0.1	0.4	0.35	0.40
0.2	0.7	1.18	0.62
0.3	2.2	2.05	1.06

* Based on change after 1 hour with 10 minute retention time in the side car; ambient F/M = 0.3

** Based on change after 12 minutes with 8.2 minute retention time in the contact chamber; ambient F/M = 0.3

*** Based on change after 12 minutes with 5.1 minute retention time in the contact chamber; ambient F/M = 0.4

A second study was undertaken to optimize the retention time in the contact chamber. Variation of the contact chamber time from 5.22 through 20.00 minutes produced no appreciable variation in the change of dissolved oxygen when measured 12 minutes after the introduction of the shock. This represents 0.44 through 1.67 retention times. The variation in retention time in the contact chamber was achieved by changing the air flow. Similarly, this variation in retention time did not produce any appreciable variation in the time required for the dissolved oxygen to have changed 0.5 ppm. These tests were run on a shock feed of 0.1 F/M. The baseline feed was at an F/M of 0.3. See Table 3 for numerical results.

TABLE 3. DETENTION TIME ANALYSIS

Detention Time, minutes	Avg. ΔDO, mg/l @ 12 min.	Time for ΔDO = 0.5 mg/l, minutes
5.11	0.98	3.6
5.22	1.08	3.3
6.92	1.16	3.0
7.03	1.19	3.6

(continued)

TABLE 3 (continued)

7.25	1.09	4.1
8.18	1.18	
10.64	1.18	2.8
20.00	1.21	3.4
Avg.	1.13± .08 (± 7%)	3.4 ± .4 (± 12%)

Next, variations in the steady state DO level were determined with operating parameters such as feed and air flow, MLVSS, etc., held constant. Fluctuations over various 12-minute periods were determined. A 12-minute period was the time span over which shock-induced DO variations were evaluated. Variations were mainly attributed to ambient temperature changes and equipment function. Table 4, steady state analysis, lists the results of the study. The average absolute value for the change in DO in a steady state system in the 12-minute period, was 0.02 mg/l DO. The standard deviation (σ), was ± 0.02 mg/l. Three σ, or ± 0.06 mg/l DO, represented a greater than 99% confidence level. That is, any change greater than 0.06 mg/l DO (in 12 minutes) is better than 99% assured of being a significant (nonrandom) variation. Random 12-minute periods were selected from a 20-hour DO chart. The initial and final DO levels were noted and a ΔDO/12-minute interval evaluated.

TABLE 4. STEADY STATE ANALYSIS*

Interval Number	ΔDO for 12 minute intervals, mg/l
1	0.04
2	0.02
3	0.00
4	-0.06
5	0.00
6	0.00
7	-0.03
8	0.06
9	-0.04
10	0.00

(continued)

TABLE 4 (continued)

11	-0.02
12	0.01
13	-0.03
14	-0.02

Avg. $|\Delta DO|$ = 0.02 mg/l O_2

σ= ± 0.02 mg/l O_2

3σ = ± 0.06 mg/l O_2

*Steady stateF/M - 0.23
Temperature range 25.9 → 24.2^{0}C (during study)

In a procedure, similar to that discussed in Appendix A for the continous respirometer, the BioMonitor was characterized with respect to response and reliability. Controlled shocks were created using solutions of powdered milk plus nitrogen and phosphorus @ 0.1 g/l $(NH_4)_2 HPO_4$. Shocks were applied for 15 minutes. The system was then returned to a baseline feed for a minimum of one hour. The results are summarized in Table 5. All DO values are an average of at least four runs.

The BioMonitor system produced a rapid response to the controlled shocks. Approximately 2/3 of the total change was experienced in 1/3 of the time span. The detention time ranged from 5.1 to 6.5 minutes. The system was reproducible (< ± 9% variation) even for runs spanning a week. The results obtained ($\Delta DO/\Delta t$ vs $\Delta F/M$) were essentially linear over the range of F/M values studied. (See correlation coefficients, Table 5).

After the BioMonitor was characterized by controlled shocks, ten different industrial wastes were tested on the system. The results of this study are given below.

Industrial Waste Shocks

The ten industrial wastes employed in this study and their chemical composition, when known, are given in Table 6. These industries were selected from a poll conducted by EPA regional offices. Priority was given according to past experience with on-line industries causing upsets in WWTP's. These were actual raw industrial wastes. According to the results from the continuous respirometer study, no acclimation period was provided. The shocking procedure was identical in each case. The specifics were as follow:

- A baseline milk feed was prepared at an F/M of 0.23.

TABLE 5. RESULTS OF CHARACTERIZATION STUDIES - BIOMONITOR

F/M change, units	Avg. ΔDO @ 4 min.	% variation	Avg. ΔDO @ 12 min.	% variation	$\frac{\Delta DO\ @\ 4\ min}{\Delta DO\ @\ 12\ min} \times 100$
0.1	0.25	± 16	0.40	± 12	63
0.2	0.39	± 5	0.62	± 6	63
0.3	0.71	± 5	1.06	± 8	67
Avg.	0.23*	± 8.7	0.35*	± 8.7	64.3

Ratio: F/M change 1 : 2.0 : 3.0
ΔDO @ 4 min. 1 : 1.6 : 2.8
ΔDO @ 12 min. 1 : 1.6 : 2.7

Correlation Coefficients for 1st order fit

F/M change vs ΔDO @ 4 minutes = 0.975

F/M change vs ΔDO @ 12 minutes = 0.982

*Avg. ΔDO, ppm, per 0.1 F/M change.

TABLE 6. IDENTITY AND COMPOSITION OF THE 10 INDUSTRIAL WASTES EMPLOYED

General Industrial Category	Specific Industry	Chemical Constituents*	
		BOD (mg/l)	Others (mg/l)
Synthetic Rubber	Synthetic Rubber	75	150 (TSS); 124 (VSS); 30 (NVSS)
Dairy	Milk, Custards, Cottage Cheese	1200	300 (TSS)
Pulp Mill	Sulfite Process	7000	
Poultry	Slaughter & Dressing	1000	
Textile	Natural Fibers	800	1600 (COD)
Tannery	Baseball Covers	1700	4000 (COD); 2600 (SS); 3000 (TVS); 10,000 (TS); 400 (O & G); 6 (Cr^T)
Meat Packing	Pork, Beef (includes blood & fats)	900	2000 (COD)
Chemical	Pesticides	(Oil & Grease) 1	Cr^{TOT} 35; Fe 0.4; Ni 4; Cu 0.4
Electroplating	Cr, Fe, Ni, Cu		
Food Processing	Chili & Similar Foodstuffs		

*Data supplied by contributing industries.

> Samples of wastes were prepared according to percent by volume formulae with the milk feed. At least three different concentrations of each industrial waste were run. Shock loadings were applied for a 15 minute period. Baseline feed was then applied for at least 15 minutes before another shock load was introduced.
> All shock loadings were performed at least in duplicate.

The above testing procedure permitted an industrial waste to be analyzed in one day. A rapid test procedure was important since most raw wastes will degrade with time. A degraded waste presented two problems. First, it became less representative of the industry from which it was received. Secondly, it would be improper to compare microorganism response at different percent shocks if the nature of the wastes had altered from one test to the next. This procedure eliminated any variation due to differences in the baseline milk feed used for dilution. The milk feed was prepared daily in one-day samples. This also eliminated variation in aeration basin solids concentration.

The results are summarized in Tables 7, 8, and 9. Table 7 compares the ratio of the percent by volume shocks with the ratios of the changes in DO observed. Table 8 shows the level of reproducibility obtained in this study. Table 9 compares the ratio of the changes in DO with the ratios of the changes in BOD from the shock load. Prior to a meaningful discussion of these results, the question of physical oxygen transfer (K_La) versus microorganism respiration must be considered. The basis of the BioMonitor response is the change in microorganism respiration causing a change in ambient DO level when the influent substrate changes. The change in DO should therefore predominately reflect the change in oxygen utilization by the biomass i.e., the oxygen transfer, in the baseline feed and in the stock load should be essentially the same during the time period of interest. To determine the constancy of oxygen transfer, the K_La (oxygen transfer coefficient) was determined in the BioMonitor contact chamber using baseline feeds and shock loading wastes. Nitrogen gas was used as the deoxygenating medium. The results are seen in Table 10. There was no significant variation in K_La among the various concentrations of a given industrial waste feed and the corresponding baseline feed. The average percent variation for the nine wastes studied plus a separate baseline feed investigation was ± 5.0% from a range of ± 1.1 to ± 7.8%. Therefore, it was assumed that changes in the DO can be attributed for the most part, to changes in the microorganisms' utilization of dissolved oxygen. When the K_La was run, a second set of shock procedures (analogous to the first) were carried out. This was performed a day later and not in duplicate. The results are seen in Table 8. Given the possible variations in stock waste solutions (due to age), baseline feed concentration and solid levels, the reproducibility of Table 8 is generally good. It should be noted that K_La values were not obtained on the food processing waste. This data comes from a second set of runs made at a later time. While K_La values were obtained for the poultry wastes, the second set of shock runs was not performed.

Before reviewing the experimental results from each industrial waste,

TABLE 7. SUMMARY OF INDUSTRIAL WASTE SHOCKS

Industrial Waste	(%shock)	Avg. ΔDO @ 4 min	Avg. ΔDO @ 12 min	Average[1] % return	Average $\frac{\Delta DO\ @\ 4}{\Delta DO\ @\ 12}$ x 100
Food Processing	(5)	-0.13	-0.35[2]	53[3]	43[4]
	(10)	-0.13	-0.43		
	(20)	-0.32	-0.95		
Synthetic Rubber	(10)	0.10	0.18	85	61
	(25)	0.26	0.37		
	(50)	0.18	0.30[5]		
Dairy	(5)	-0.11	-0.24	83	55
	(10)	-0.18	-0.36		
	(25)	-0,41	-0.79		
	(50)	-0.60	-1.20		
Pulp Mill	(2)	-0.25	-0.35	81	54
	(5)	-0.34	-0.63		
	(10)	-0.36	-0.80		
Poultry	(5)	-0.06	-0.14	see text	42
	(20)	-0.12	-0.30		
	(50)	-0.19	-0.44[6]		
Textile	(5)	-0.38	-0.50	91	73
	(10)	-0.59	-0.79		
	(20)	-0.78	-1.20		
Tannery	(5)	-0.35	-0.50	57	57
	(10)	-0.35	-0.50		
	(20)	-	-		
Meat Packing	(10)	-0.08	-0.19	39	52
	(20)	-0.14	-0.30		
	(50)	-0.36	-0.59		
Chemical	(5)	0.10	0.14	79	68
	(20)	0.13	0.20		
	(50)	0.36	0.50		
Electroplating	(10)	0.33	0.45	96	67
	(30)	0.65	0.88		
	(50)	0.76	1.05		
					50 grand average

[1] % return is the ratio of |ΔDO obtained from shock A going back to baseline feed @ 12 min/ΔDO obtained from baseline feed going to shock A @ 12 min| x 100

[2] sign indicates direction of change in DO level with application of shock loading

[3] grease

[4] older unit

[5] acclimation

[6] in only

TABLE 8. REPRODUCIBILITY OF INDUSTRIAL SHOCKING RESULTS

(% Shock)	Run I ΔDO Avg @4 min	Run I ΔDO Avg @12 min	Run II ΔDO Avg* @4 min	Run II ΔDO Avg* @12 min
Food Processing				
(5)	.13	.35	-	-
(10)	.13	.43	.26	.50
(50)	.32	.95	.43	.94
Dairy				
(5)	.11	.24	-	-
(10)	.18	.36	.21	.44
(25)	.41	.79	.40	.74
(50)	.60	1.20	.60	1.30
Poultry				
(5)	.06	.14	(see text)	
(20)	.12	.30		
(50)	.19	.44		
Tannery				
(5)	.35	.50	.18	.29
(10)	.35	.50	.36	.72
(20)	-	-	.53	1.13
Chemical				
(5)	.10	.14	.08	.17
(20)	.13	.20	.13	.20
(50)	.36	.50	.32	.46

(% Shock)	Run I ΔDO Avg @4 min	Run I ΔDO Avg @12 min	Run II ΔDO Avg @4 min	Run II ΔDO Avg @12min
Synthetic Rubber				
(10)	.10	.18	.54	.74
(25)	.26	.37	.62	.80
(50)	.18	.30	.51	.74
Pulp Mill				
(2)	.25	.35	.22	.30
(5)	.34	.63	.30	.60
(10)	.36	.80	.36	.77
Textile				
(5)	.38	.50	.34	.50
(10)	.59	.79	.49	.79
(20)	.78	1.20	.80	1.35
Meat Packing				
(10)	.08	.19	.04	.13
(20)	.14	.30	.05	.24
(50)	.36	.59	.29	.64
Electroplating				
(10)	.33	.45	.20	.34
(30)	.65	.88	.48	.72
(50)	.76	1.05	.82	1.24

*Run I data is obtained from the shock load run;
Run II data is obtained from the K_La runs.

TABLE 9. DATA SUMMARY - RATIOS OF CORRESPONDING BOD VARIATIONS AND DO VARIATIONS DURING SHOCK LOADING

Waste	Shock Ratio	ΔDO ratio @ 4 min	ΔDO ratio @ 12 min	BOD ratio baseline feed:shock 1: shock 2:shock 3
Tannery	1:2:4	1:2.0:2.9	1:2.5:3.9	1:1.8:2.6:4.2
Electroplating	1:3:5	1:2.0:2.3	1:2.0:2.3	N/A
Food Processing	1:2:4	1:1:2	1:1.3:2.4	N/A
Synthetic Rubber	1:2.5:5	1:2.6:1.8	1:2.1:1.7	1:0.98:0.94:0.88
Dairy	1:2.5:10	1:1.6:3.7:5.5	1:1.5:3.3:5.0	1:1.5:2.1:3.8:6.5
Pulp Mill	1:2.5:5	1:1.4:1.4	1:1.8:2.3	1:2.4:4.4:7.9
Poultry	1:2:4	1:2:3.2	1:2.1:3.1	1:1.1:1.4:1.9
Textiles	1:2:4	1:1.6:2.1	1:1.6:2.4	1:1.4:1.7:2.4
Meat Packing	1:2:3	1:1.8:4.5	1:1.6:3.1	1:1.8:2.6:5.0
Chemical	1:4:10	1:1.3:3.6	1:1.4:3.6	1:1.02:1.10:1.25
Baseline feed (F/M variations)	1:1.3:2.4		1:1.5:2.3	1:1.3:2.4

TABLE 10. K_La STUDY ON 10 INDUSTRIAL WASTES

Waste	K_La mean*	σ, standard deviation ±	± %
Baseline feed**	0.253	0.003	1.1
Synthetic Rubber	0.231	0.018	7.8
Dairy	0.190	0.015	6.5
Pulp Mill	0.337	0.017	5.0
Poultry	0.254	0.009	3.5
Electroplating	0.253	0.008	3.2
Textiles	0.267	0.017	6.4
Tannery	0.294	0.011	3.7
Chemical	0.292	0.012	4.1
Meat Packing	0.298	0.014	4.7
Average for wastes			5.0

*Includes K_La's determined for both % shocking wastes and corresponding alternating baseline milk feed.

**No wastes.

a few general comments can be made. For most wastes, the BioMonitor began to show a detectable response within 30 seconds of the application of the shock into the system. The time periods of four minutes and 12 minutes for evaluating ΔDO were chosen because this represented approximately one-half the retention time of the contact unit and two retention times of the contact chamber, respecitvely. Also, it should be noted that the values for the percent shocks used for each of the ten industrial wastes resulted from the desire to obtain a reasonable range of ΔDO values during the experiment. As such, each of the percent by volumes was determined individually for each of the ten industries.

The steady state evaluation yielded a 3 σ value of ± 0.06 mg/l DO/12 minute interval. The average absolute value of the ΔDO for an industrial shock after 12 minutes was 0.30 mg/l for the minimum changes (lowest % shock) for each waste, and .78 mg/l (highest % shock) for the maximum change for each waste with a range of 0.14 to 1.20 mg/l O_2. Therefore, we concluded that the changes in DO level effected by the shock loadings were significant. Moreover, the response from the lowest percent shock applied after a 4 minute period exceeded the 0.06 mg/l O_2 in each case except for the poultry waste where it equalled 0.06 mg/l O_2. The range was 0.06 - 0.35 mg/l O_2.

Food Processing Waste--

Introduction of this waste produced a decrease in DO level as anticipated. This was a function of the high BOD content as well as the lack of inhibitory factors. The actual BOD of the waste was not known. The industry produced canned convenience foods. Their sewage charge was based on a BOD of 300-400 mg/l. However, the source of the waste used in this experiment was an in-line grease pit. The site was selected for ease of sampling. The BOD was considerably higher. The percent return is defined as the ratio of |ΔDO obtained from shock A going back to baseline feed @ 12 min/ΔDO obtained from baseline feed going to shock A @ 12 min | x 100. The return is low because of grease coating the interior of the contact chamber. When the shock load was removed and the baseline feed restored, the system was still experiencing a higher BOD level due to this residual grease coating. Also, the DO probe membrane was frequently changed to prevent malfunctioning from grease buildup on the surface.

Rubber Waste--

The waste is the raw effluent from a new synthetic rubber manufacturing plant. Upon introduction of this waste the DO increased, reflecting the overall decreased BOD loading and perhaps the inability of the microorganism to utilize the available BOD. There are no synthetic rubber plants discharging into the WWTP whence our biopopulation came. The decrease in magnitude of the DO change at a 50% (Table 7) by volume shock could indicate a preliminary acclimation of the microorganisms to the available industrial BOD. This decrease in DO change is again exhibited in the data obtained during the K_La studies (Table 8).

Dairy Waste--

As anticipated, there were no problems or anomalies experienced with the dairy waste tested. All aspects can be accounted for such as the decrease in DO values, good percent returns (83%), good reproducibility. This dairy does not discharge the whey from cottage cheese manufacturing. Milk and custards (seasonally) are also produced there.

Pulp Mill Wastes--

The industrial source was a sulfite process plant. The pulp mill wastes contained a very high BOD, (7000 mg/l). As evidenced by the low percent by volumes used in the experiment the waste was very "strong." The large ΔDO indicated easy utilization of the ambient BOD by the unacclimated biomass.

Poultry Waste--

Inexplicably, the poultry waste proved the most problematic of the ten wastes. Despite the high BOD and its ostensibly noninhibitory nature, the change in DO was positive (increase) upon application of a shock load, reflecting inhibition. The shock load experiments were run twice. Both series of tests produced anomalous behavior. The initial results are given below. They were essentially the reverse of what would be anticipated.

TABLE 11. POULTRY WASTE SHOCK LOADING-EXPERIMENT 1

% shock	ΔDO @ 4 min	ΔDO @ 12 min	Average % return	ΔDO @ 4 min / ΔDO @ 12 min
5	0.88	1.20	101	74
10	0.84	1.10	104	76
20	0.69	0.91	114	75
Avg.			106	75

A second test was performed to verify these unexpected results. The findings are reported in Tables 11 and 12. As originally anticipated, the DO now decreased with the application of the shock and the magnitude of the change increased with increasing shock strength. However, the "% return" after removal of the shock was generally not very good and very erratic with respect to both magnitude and sign. This could be attributed to a natural grease in the waste but the cause was hard to establish in conjunction with the other unexpected behavior. Table 12 lists the detailed results of the second poultry waste analysis. "To 5%" means the change from baseline feed to a 5% by volume poultry waste shock; "from 5%" means the return from the 5% shock load to the baseline feed.

Since the source of this waste was not local, it proved impossible to follow up our investigation with questions of the poultry plant personnel and/or additional samples for further analysis.

Textile Waste--

The textile waste came from a natural fibers plant. They employed no carriers or chromium dyes. The results were straightforward and predictable from the BOD concentration. The shock runs employing this waste exhibited excellent reproducibility. The average percent return, 91%, was likewise excellent.

TABLE 12. POULTRY WASTE SHOCK LOADING-EXPERIMENT @

% shock	ΔDO @ 4 min	ΔDO @ 12 min	% return	ΔDO @ 4 min / ΔDO @ 12 min
to 5%	-0.05	-0.13	15	38
from 5%	-0.03	-0.02		--
to 5%	-0.07	-0.16	75	44
from 5%	-0.03	-0.12		(25)
to 20%	-0.12	-0.30	-23	40
from 20%	0.02	0.07		(28)
to 50%	-0.25	-0.57	-63	44
from 50%	0.11	0.36		(31)
to 50%	-0.13	0.30	75	43
from 50%	0.20	0.40		(50)
|Average|			50	42(33) 38

Tannery Waste--

This waste was the effluent from the manufacture of baseball covers. The high BOD (1700 mg/l), and COD (4000 mg/l), were easily accounted for in the resultant DO decrease. The result from the K_La study producéd the more linear response anticipated. The percent return, however, is not very high. Again, this probably reflects the relatively high oil and grease content of the waste (400 mg/l). The solids and chromium content had no distinguishable effect on the response.

Meat Packing Waste--

This meat packing waste came from a plant which did not reclaim blood and fats. The presence of the former in the waste could account for the relatively small decrease in DO level for large changes in loading. Although the BOD was about 900 mg/l (cf the changes induced in the DO by a textile waste with a BOD of 800 mg/l) there was inhibition possible from the high TDS contribution of the blood. The presence of fats caused return. These results were reproduced in the K_La runs.

Chemical Waste--

This waste came from the manufacture of pesticides. The BOD value of 150 mg/l was a result of analyses with acclimated seed. The COD is 2500 mg/l. The increase in DO level upon introduction of the shock was anticipated. Importantly, the system was not "knocked out" during the runs. The results showed a steady increase with increasing percent shock load. These values were very reproducible also (Tables 7 and 8).

Electroplating Waste--

The electroplating facility used in this test discharged negligible BOD in their raw waste. This is reflected in the sharp increase (cf response to chemical waste) in DO upon shock loading. Since the system exhibited an excellent percent return, (96%) it is assumed that no permanent damage was incurred by the viable biomass even with the relatively high total chromium content.

ON-SITE INVESTIGATIONS

The BioMonitor was to be located at two joint wastewater treatment plants. Specific criteria had to be met by those WWTPs selected. It was required that the plants selected:

- treat sanitary (municipal) sewage and industrial wastes
- employ biological treatment - preferably activated sludge
- be in routine running form
- experience possible upsets from a known industrial contribution
- preferably have a flow < 10 MGD (so events could be sorted and analyzed for research purposes)
- preferably have an industrial contributor amenable to the positioning of a companion BioMonitor at their discharge point
- have analytical and operational data available.

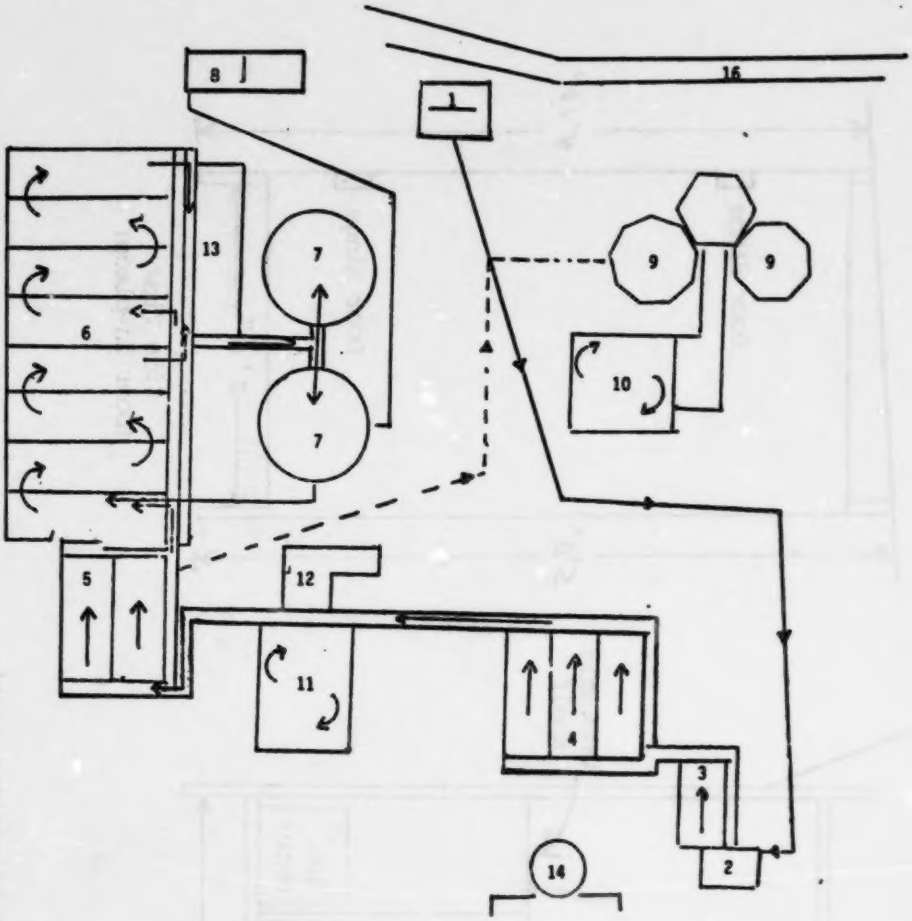
Site Set One

Description of Joint Municipal/Industrial Wastewater Treatment Plant 1 and the BioMonitor Setup--

The BioMonitor system was set up at an activated sludge-type wastewater treatment plant which is part of Metro Nashville's system. The daily flow is 3 MGD (capacity, 6 MGD). Figure 5 is a diagram of the wastewater treatment facility. The BioMonitor, set up in a newly designed enlarged "monitor" station (see Figure 6), was located on the "influent structure." (See Figure 6) for relative location). Figure 7 is a picture of the BioMonitor on location. Flow time from its location to the aeration basin was approximately 3 hours.

At this point, the waste stream has been through preliminary screening and the bar minutors (maximum solids size ≈ 1"). Suspended solids still remained a problem in that they tended to clog the pump tubing. The screening device shown in Figure 8 eliminated this problem. The outside screen is common aluminum house screening. The interior screen is a stainless steel mesh with openings of 0.004". Since the waste flow was ≈ 12 feet beneath the influent structure the feed tubing was contained in a metal conduit and the entire apparatus was weighted down because of the current and turbulence in the flow. Required maintenance, i.e., a hosing down to remove "caked" solids was required approximately once every 10 days to 2 weeks.

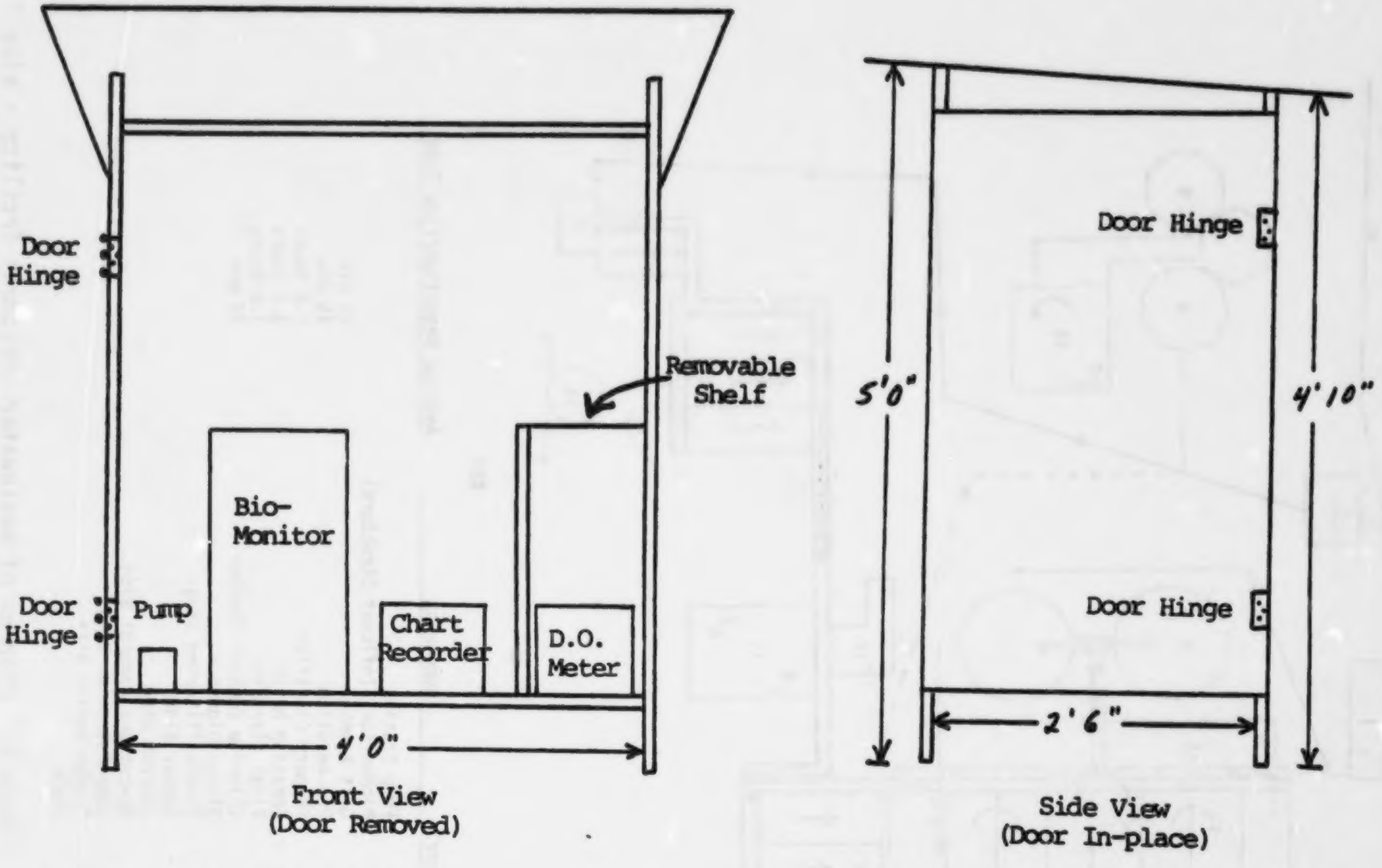
At this location, we were able to use air from the blowers used to aerate the treatment tanks. (The biopopulation for the BioMonitor was taken



KEY

Number	Component	Average Retention/Flow Time
1	Pump Station	
2	BioMonitor (Influent Structure)	
3	Grit Removal	15 min
4	Pre-Aeration	45 min
5	Primary Clarifier	1.8 hours
6	Aeration Basin	6.2 hours
7	Final Clarifier	1.8 hours
8	Chlorine Contact Chamber	45 min
9	Sludge Digester	
10	Sludge Filtering Bldg.	
11	Blower Bldg.	
12	Contact Wing	
13	Operations Control Bldg.	
14	Administration Bldg.	
15	Sludge Burial Site	
16	Creek	

Figure 5. Diagram of wastewater treatment facility - site 1.


Door Hinge
Door Hinge
Pump
Bio-Monitor
Chart Recorder
D.O. Meter
Removable Shelf
4'0"
Door Hinge
Door Hinge
5'0"
4'10"
2'6"

Front View
(Door Removed)

Side View
(Door In-place)

Figure 6. Design of monitor station.

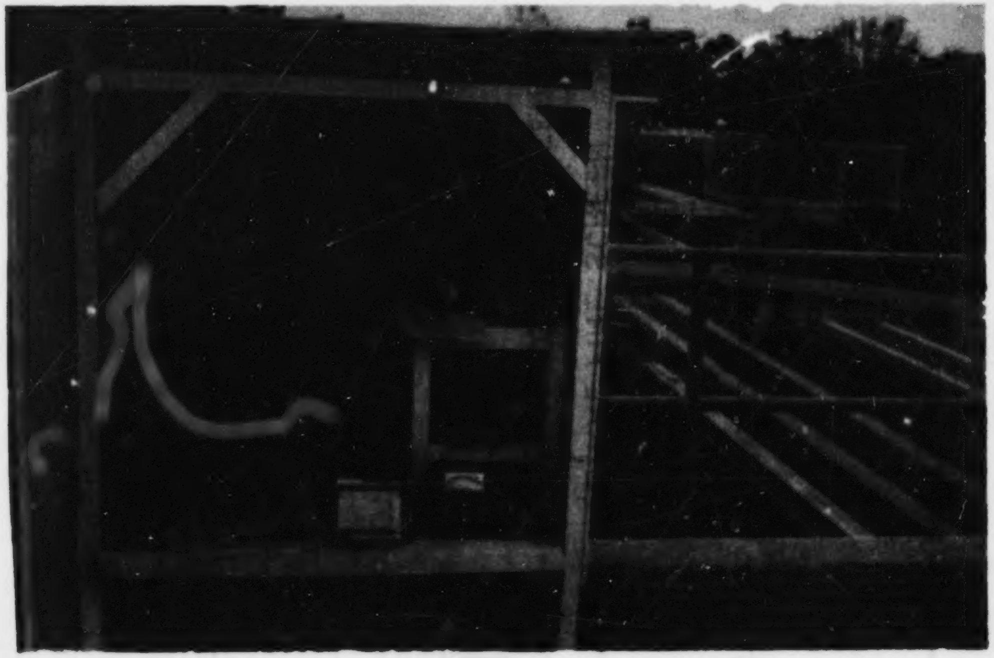


Figure 7. BioMonitor on Location - Site 1

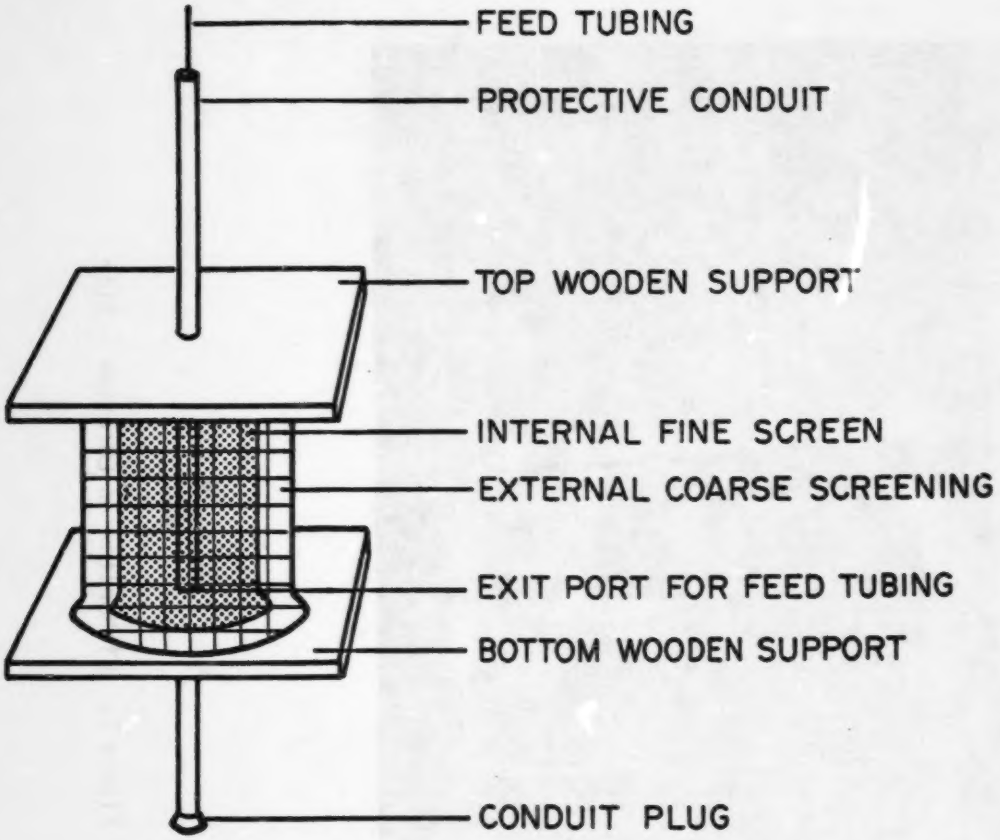

FEED TUBING
PROTECTIVE CONDUIT
TOP WOODEN SUPPORT
INTERNAL FINE SCREEN
EXTERNAL COARSE SCREENING
EXIT PORT FOR FEED TUBING
BOTTOM WOODEN SUPPORT
CONDUIT PLUG

Figure 8. Design of screening device.

from the plant's aeration basins.) The biopopulation increased in the BioMonitor system over that level held in the treatment plant's basin. Due to peculiarities in flow, the plant maintains a comparatively low biomass (900 mg/l MLSS) in order to prevent ashing during periods of low flow (which occur daily in the pm; viz: 12 midnight - 8 am flow = 2 MGD; 8 am - 4 pm flow = 4.5 MGD; 4 pm - 12 midnight flow = 3 MGD). In the BioMonitor, however, a constant feed rate was applied. Secondly, it should be noted that the plant runs at a high ambient DO in the aeration basins (7 mg/l average) in order to accommodate daily high BOD loadings discharged from a meat processing plant. Average daily influent BOD is approximately 150 mg/l. Percent removal is approximately 91%. Suspended solids (SS) average 150 mg/l. Percent removal is approximately 90%.

Description of Industrial Plant Site 1 and BioMonitor Setup--

The BioMonitor system was set up at a luncheon meat processing plant which contributes to the joint municipal system under study. The waste is composed of sanitary waste, floor washings (includes meats, fats, blood, cleaning agents, disinfectants, etc.), process water and smoker ash slurry. The industry pretreats the discharge only to the extent of skimming off fats, settling, and screening. Weekday flow rates vary from less than 400 gpm to above 800 gpm. Weekend flow rates often drop below 100 gpm. The average total daily assessed flow is 0.4 MGD. This represents over 13% of the flow to the wastewater treatment plant described above. It is the largest, single contributor. The average BOD is approximately 450 mg/l. However, recent BOD values have averaged approximately 325 mg/l. The screening device shown in Figure 9 was employed here, also. The only difference was that it was smaller. Due to the periods of low flow it was necessary to install a weir at the end of the waste trough. The minimum sampling depth was 4 inches.

The feed to the BioMonitor was diluted 1:1 with tap water. This was necessary because we wished to maintain the same retention time in both BioMonitor units and the BOD is too high in the industrial waste to permit a 100% flow at a feed rate of approximately 25 ml/min. Feed and water rates varied from 10 to 14 ml/min each for a combined range of 24 to 28 ml/min. The biomass used in the monitor system was taken from the wastewater treatment plant described above. Air to this unit was delivered from a portable compressor. Again, the DO was kept at a high level in order to accommodate the high shock loadings routinely experienced from this plant.

Operational Procedures and Data Collection--

The maintenance schedule at both locations included daily calibration of the DO probe to maintain accuracy of the results. Solids were also taken and subsequent necessary wasting performed to maintain desired levels at the wastewater treatment plant. Backwashing of the feed tubing with bleach followed by water was performed every week to keep the tubing clean and flow rates constant. Since oil and grease is a common constituent of the waste from the meat processing plant, feed line coating was experienced. Therefore, routine maintenance included backwashing the feed tubing system with isopropyl alcohol and/or acetone followed by excess water. We have experienced no difficulties with the dilution water system. Appendix D contains the maintenance procedures followed at the wastewater treatment plant and industrial sites. Included also is the daily log maintenance sheet. This level of maintenance was higher for research purposes than that proposed during actual use.

The wastewater treatment plant intermittently discharges the supernatant and filtrate from the anaerobic sludge digester and centrifugal filter directly into the water flow at the influent structure. This is an anaerobic, zero DO, contribution. The discharge is manually controlled which enabled the BioMonitor to be tested on intraplant discharges in the early stages of setup.

Figure 9 is a graph of DO versus time obtained by a 24-hour run on the BioMonitor. Points 1 and 5 represent a decrease in the DO due to domestic usage in the AM diurnal cycle. Points 2 and 3 correspond to the intraplant discharges described in the last paragraph. The volume of anaerobic waste discharged will vary. Point 4 represents a decrease in the DO due to the influx of the meat processing industry's waste. Range 6 reflects the higher DO normally found in the PM diurnal cycle due to lower usage and temperatures. Points 2, 3, and 4 coordinate well with known (recorded) times of discharge. The record of ambient DO is obtained at a rate of 7.5 inches of chart paper per hour and must be manually reduced to the more usual display presented in Figure 10 . Figures 10 and 11 are a set of early graphs of the DO levels at the industrial site and wastewater treatment plant, respectively. These graphs represent the same date and time period. The sharp decrease in DO level experienced at the meat processing plant begins at approximately 6:00 a.m. It was first seen in the wastewater treatment plant BioMonitor at approximately 7:30 a.m. (beginning of DO sag). The steady increase in DO from about 11:00 p.m. (in Figure 11) reflects p.m. diurnal cycle of low temperatures and usage. The decrease at approximately 1:30 a.m. most likely corresponds to the intraplant discharge of anaerobic filtrate/supernatant from the digester. Figure 10 from the meat processing plant indicates some plant discharge at approximately midnight with the DO leveling off until the large 6:00 a.m. shock. The second shift at the plant comes on duty at midnight. The sanitation (or clean up) crew is on duty between 10:30 p.m. and 7:00 a.m.

Tables 13 and 14 give the operating parameters for the two companion BioMonitors at the wastewater treatment plant and industrial site, respectively. Effort was extended to run the systems as similarly as possible. Consideration was also afforded to the WWTP's operating procedure. Whenever possible the operating parameters of the WWTP were employed in the operation of the BioMonitor.

These operating parameters represent the culmination of efforts to establish the BioMonitor as a steady, routinely operating system. Following this period of troubleshooting the system, a period of intensive data collection was provided at both sites. Appendix D contains the sampling routines for both sites. Appendix E contains the complete set of results (graphically) of this data collection period. Two periods of intensive data collection were planned. These periods were each 5 days long and each day of the week was included at least once. At these times, 24-hour surveillance was maintained at both sites. Composite (every 20 minutes for an hour) samples were gathered manually. When the recorder indicated a change in DO level, grab samples were taken. Samples were collected from the influents to the BioMonitor at both the meat processing plant and at the wastewater treatment

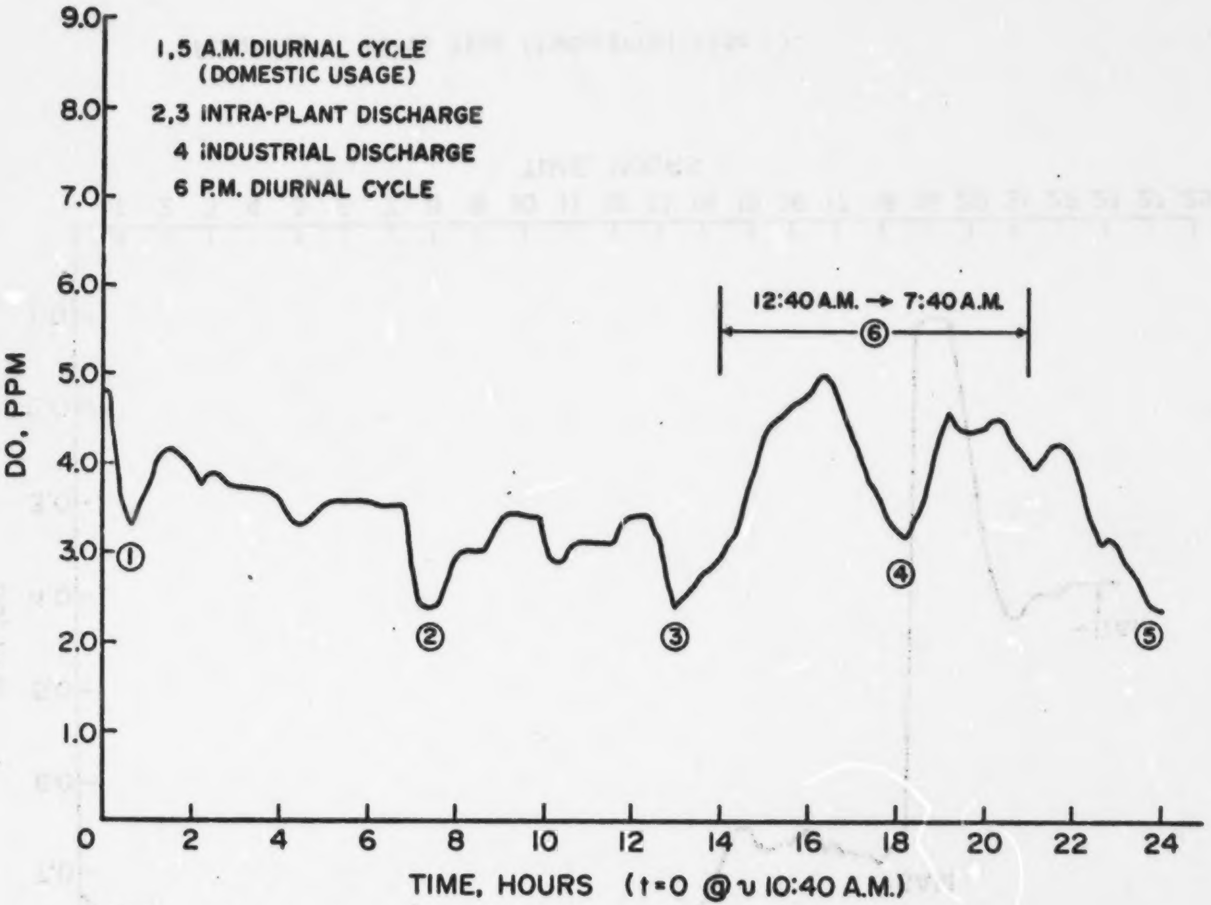


Figure 9 . Preliminary graph - BioMonitor response - joint wastewater treatment pla[illegible] - site 1.

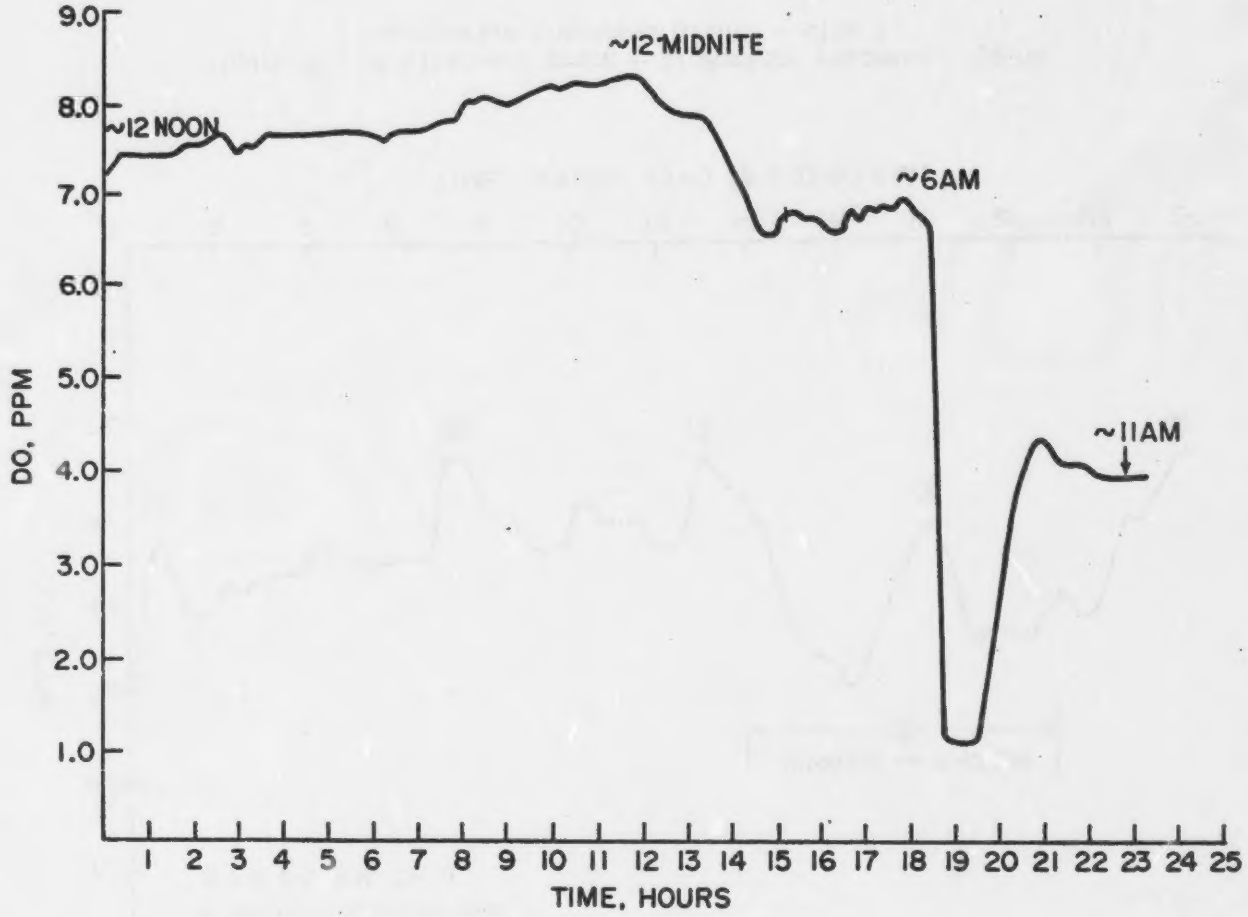


Figure 10 . DO vs time (industrial site 1).

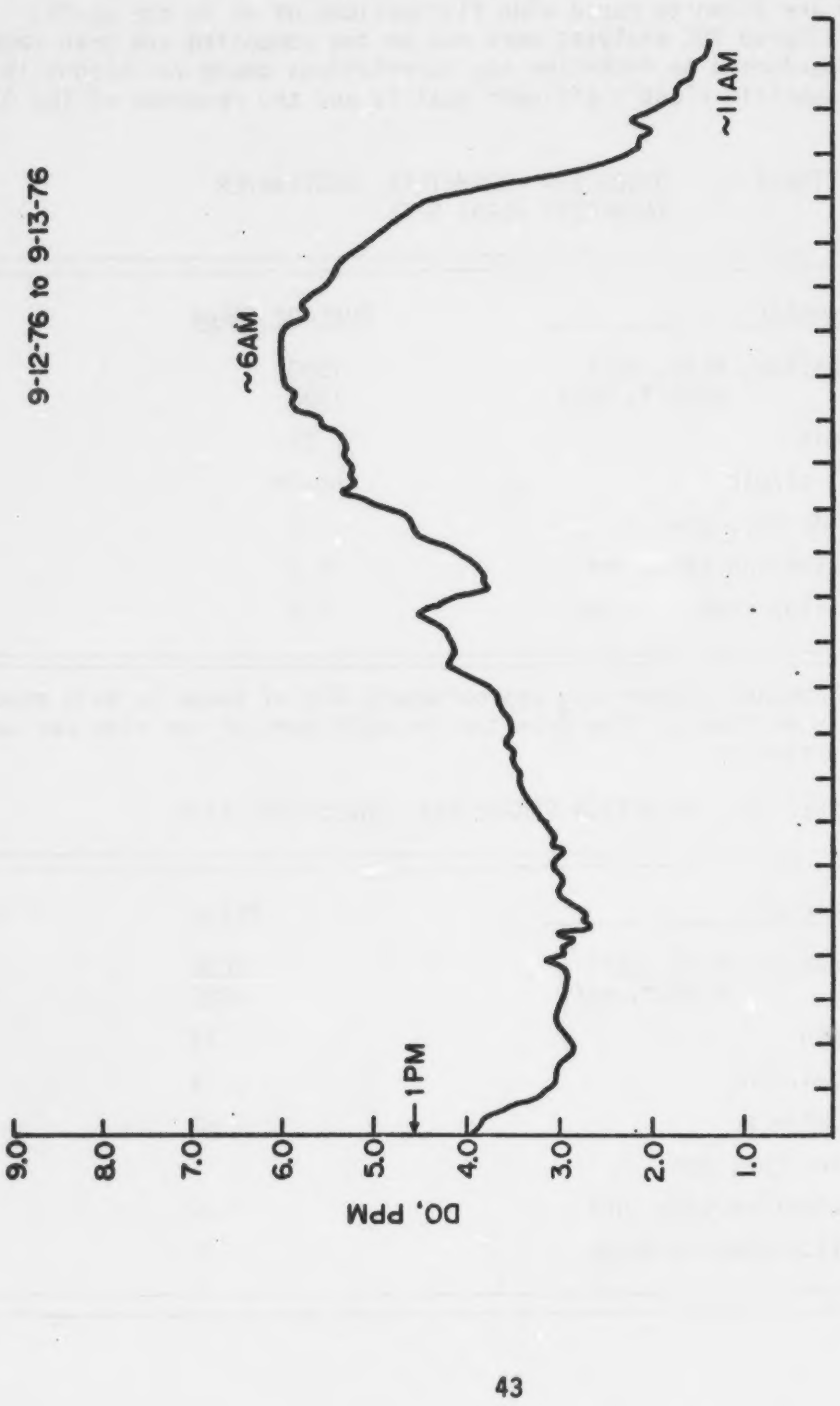


Figure 11. DO vs time (wastewater treatment plant - site 1).

plant. Additional samples similarly composited over one hour were taken from the final effluent of the wastewater treatment plant. Oxygen uptakes were performed hourly on the biomass from one of the aeration basins at the wastewater treatment plant. A recording pH meter continuously monitored the pH of the influent to the system at the meat processing plant. The presence of cleaning agents are known to cause wide fluctuations of pH in the waste. Acidified and filtered TOC analyses were run on the composite and grab samples. This study was performed to determine any correlations among variations in loading in the specific plant's effluent quality and the response of the BioMonitor.

TABLE 13. OPERATION PARAMETERS: WASTEWATER TREATMENT PLANT SITE

Parameter	Average Value
Solids, main reactor, MLSS, mg/l	1500
MLVSS*, mg/l	1300
Feed flow, ml/min	25
Return flow**, ml/min	65-70
Baseline DO, side car, ppm	4
Main reactor retention time, hrs	6.5
Side car, retention time, minutes	5.5

*MLVSS in the contact chamber avg approximately 80% of those in main reactor

**Return flow is defined as flow from the top exit port of the side car back into the main reactor

TABLE 14. OPERATION PARAMETERS: INDUSTRIAL SITE

Parameter	Value
Solids, main reactor, MLSS, mg/l	2000
MLVSS*, mg/l	1800
Feed flow, ml/min	13
Dilution flow, ml/min	13
Return flow**, ml/min	80
Baseline DO, side car, ppm	3
Main reactor retention time, hrs	6.5
Side car retention time, minutes	5

*MLVSS in contact chamber avg approximately 80% of those in main reactor
**Return flow is defined as flow from the top exit port of the side car back into the main reactor.

This data can be seen in Appendix E. Data from the meat processing industry will help substantiate the preliminary data on lag times, degree of DO decline and also indicate a possible source and extent of a high BOD loading. The correlation of the change in influent TOC to change in DO was demonstrated.

The DO and TOC values from the same sampling point are drawn on the same graph so response and correlation can be visually assessed. The variations in the TOC graphs are exaggerated because they are plotted from hourly composites. The DO graphs vary more smoothly since they reflect continuous monitoring. Temperatures are listed periodically on the X-axis. This indicates the direction of thermal influence on the observed trends in DO level.

The following conclusions were drawn from this data:

- There is generally good correlation between TOC values and DO at both the industrial and WWTP sites. The industrial response, by the nature of the discharge, is the more dramatic.
- Evaluation of WWTP influent/effluent TOC values indicate a range of flow times ranging from 5 to 10 hours. This is in agreement with plant design and known variations in flow. The TOC values obtained in our study (plant influent and effluent) are consistently higher than those reported by the metropolitan government.
- The average TOC required to change the DO level one (1) mg/l at the industrial BioMonitor is 496 ± 33 mg/l. Evaluation of this TOC requirement at the WWTP lead to the discovery of two distinct influents. Specifically, there is one waste that has a value of 70.2 ± 11% mg/l TOC for a 1 mg/l change in DO and a second waste with a value of 175 ± 22% mg/l TOC. The probability that these groups of values result from an actual difference in the influent is greater than 99.5%.
- The sewer flow time from one BioMonitor to the second unit ranged from 1.5 to 3 hours as measured by peaks in DO. This again agrees well with the unreported Metro time of flow studies of 2 to 3 hours.
- The early afternoon TOC peak at the industrial site appears to be production intensive (i.e., which products are being prepared). It routinely appears but has more variation in its peak time than the midnight or 6 a.m. peaks. The decrease in activity at the plant on Sunday is clearly seen. A somewhat different profile can also be seen at the WWTP on weekends.

Site Set Two

Description of Joint Municipal/Industrial Wastewater Treatment Plant 2 and BioMonitor Setup--

The second municipal site is also a Metro Nashville Wastewater Treatment facility which employs activated sludge for biological treatment. It is a new plant (operating for approximately 1 year at the time of this investigation) with a design hydraulic load of 25 MGD. Current flow is approximately 10-12 MGD. Figure 12 is a diagram of the facility. The BioMonitor station was located on the channel after the grit removal structure (see location on Figure 13). Figures 13 and 14 are pictures of the BioMonitor setup at this site. Because of colder weather conditions a heat lamp was installed in the monitor station to prevent system freezing. The main problem was freezing of the effluent line after it left the protection of the station. It appeared the influent raw waste was sufficiently warm to prevent influent line freezing.

The influent solids level at this municipal site was higher than that encountered at the first municipal site. The problem of feedline clogging was continuously encountered with the screening system employed at site one. Therefore, a different screening device was required. Figure 15 is a diagram of the new device. Figure 16 gives an actual perspective of the screening device in use. All other aspects of the setup were identical to those used at the first wastewater treatment plant.

The average operating parameters of this second WWTP are given in Table 15. Sludge from primary and secondary treatment is piped to the Metro Central facilities where it is combined with Central's waste and incinerated.

Description of Industrial Site 2 and BioMonitor Setup--

The second industrial site was an industry which manufactured projectiles for 106 millimeter shells. The wastewater included heavy metals, proprietary cleaning and wetting agents (TOC source) and acids (e.g., chromic, phosphoric). The wastewater analysis used for sewerage charges is given in Table 16. Although the TOC concentration was significant, the BOD averaged less than 30 mg/l. Therefore, the plant's waste stream feed was diluted 1:1 with a milk solution before entering the BioMonitor. The milk created an F/M of approximately 0.25. The screening device was similar to the one described in Figure 8. Because of minimal solids problem and nonturbulent flow in the waste trough, only one screen (the fine mesh one) was required.

The plant was run on two shifts and operated from approximately 6 a.m. to 11 p.m. (when it is locked up), 5 days per week. The plant was closed weekends. Other work is performed at this location but the resultant aqueous waste streams are small and segregated. It was not anticipated that the variations observed via BioMonitor readings would be identifiable at the WWTP. It was possible, however, due to the toxic nature of various waste stream constituents, that a singularly large spill, etc., could impact the WWTP adversely. This did not occur during the monitoring period.

Operational Procedures and Data Collection--

The two companion BioMonitors were stabilized in their new locations. When daily results indicated a properly functioning system, another intensive data collection period was begun. Operating parameters were similar to those given in Tables 13 and 14.

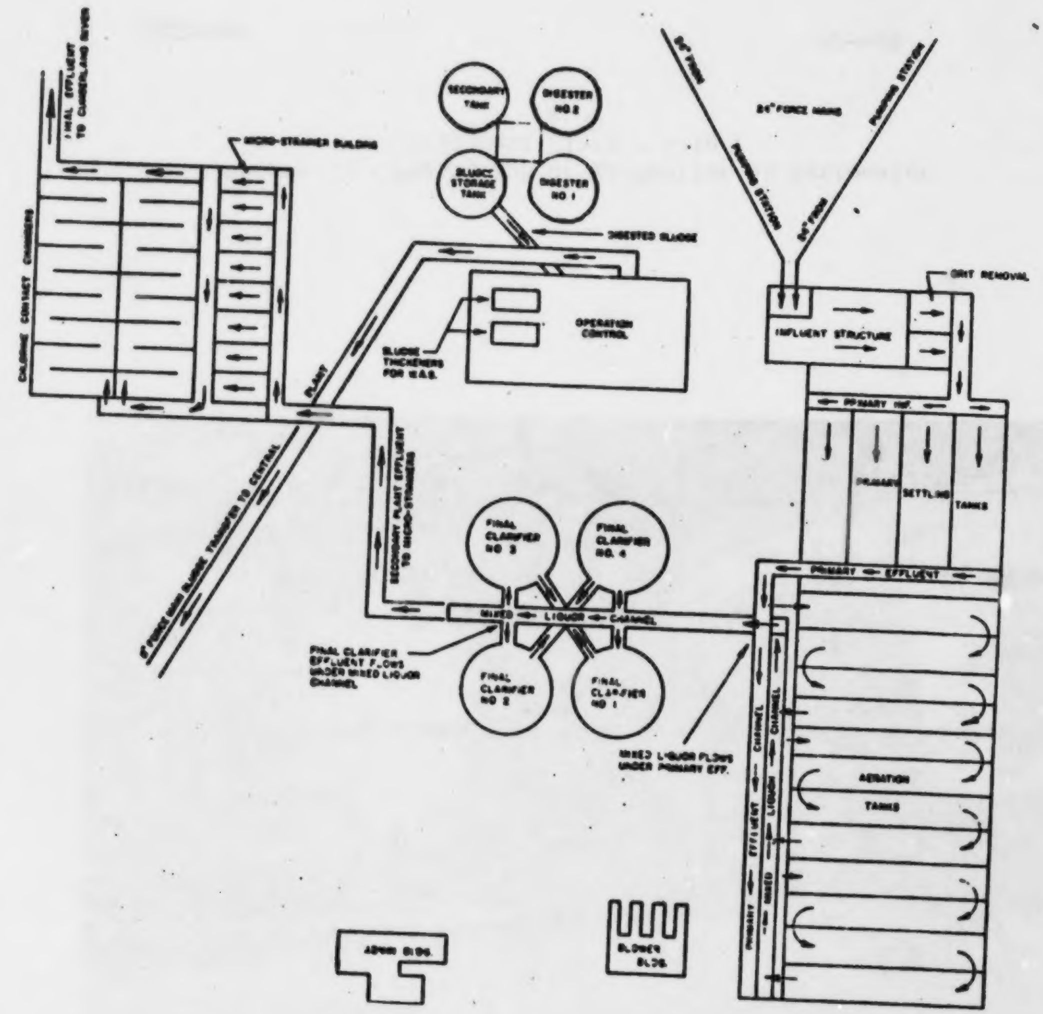

FINAL EFFLUENT TO CUMBERLAND RIVER
MICRO-STRAINER BUILDING
CHLORINE CONTACT CHAMBERS
SECONDARY TANK
DIGESTER NO 2
SLUDGE STORAGE TANK
DIGESTER NO 1
DIGESTED SLUDGE
OPERATION CONTROL
SLUDGE THICKENERS FOR W.A.S.
PLANT
6" FORCE MAIN SLUDGE TRANSFER TO CENTRAL
SECONDARY PLANT EFFLUENT TO MICRO-STRAINERS
FINAL CLARIFIER NO 3
FINAL CLARIFIER NO. 4
FINAL CLARIFIER NO 2
FINAL CLARIFIER NO 1
MIXED LIQUOR CHANNEL
FINAL CLARIFIER EFFLUENT FLOWS UNDER MIXED LIQUOR CHANNEL
MIXED LIQUOR FLOWS UNDER PRIMARY EFF.
24" FROM
24" FORCE MAINS
PUMPING STATION
PUMPING STATION
24" FROM
GRIT REMOVAL
INFLUENT STRUCTURE
PRIMARY INF.
PRIMARY SETTLING TANKS
PRIMARY EFFLUENT
AERATION TANKS
PRIMARY EFFLUENT CHANNEL
MIXED LIQUOR CHANNEL
ADMIN BLDG.
BLOWER BLDG.

Figure 12. Wastewater treatment facility - site 2.

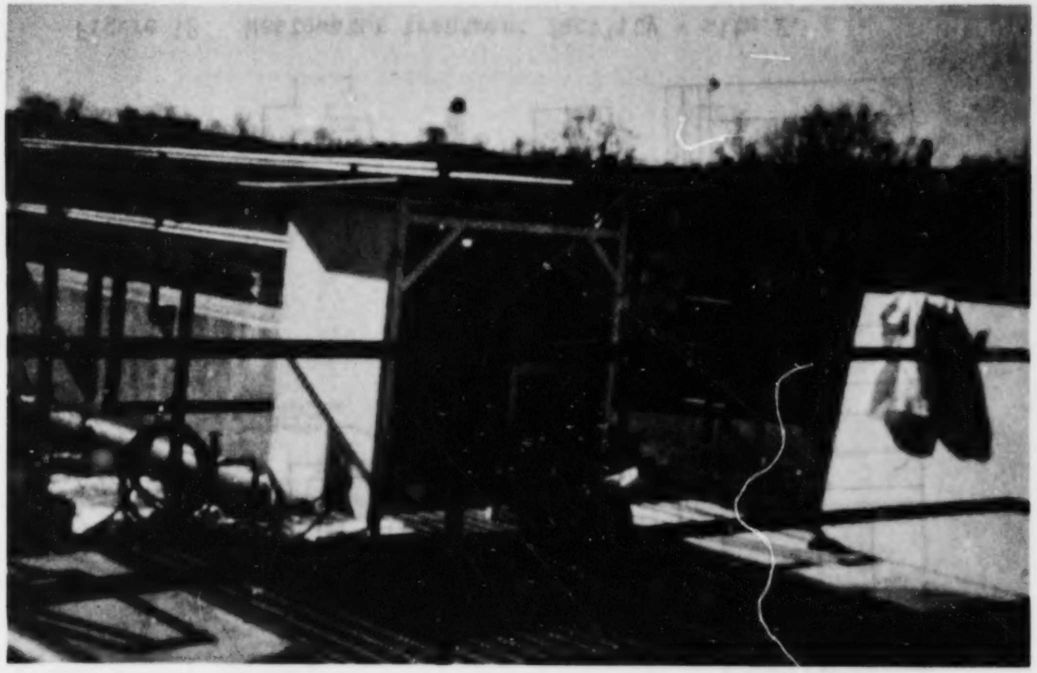


Figure 13. Photograph of BioMonitor at Wastewater Treatment Plant - Site 2

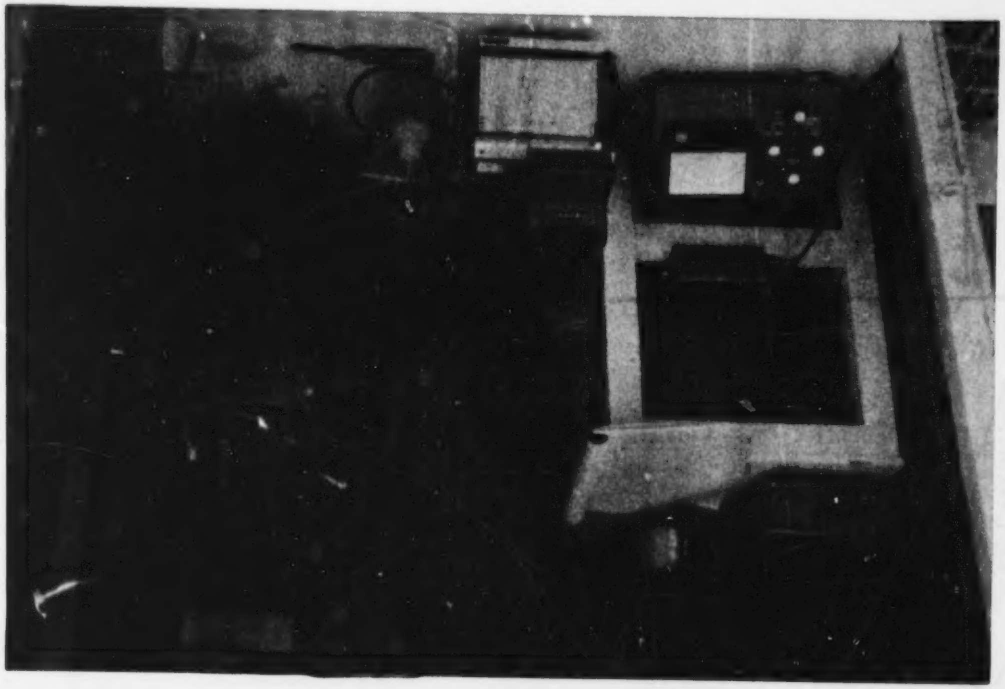
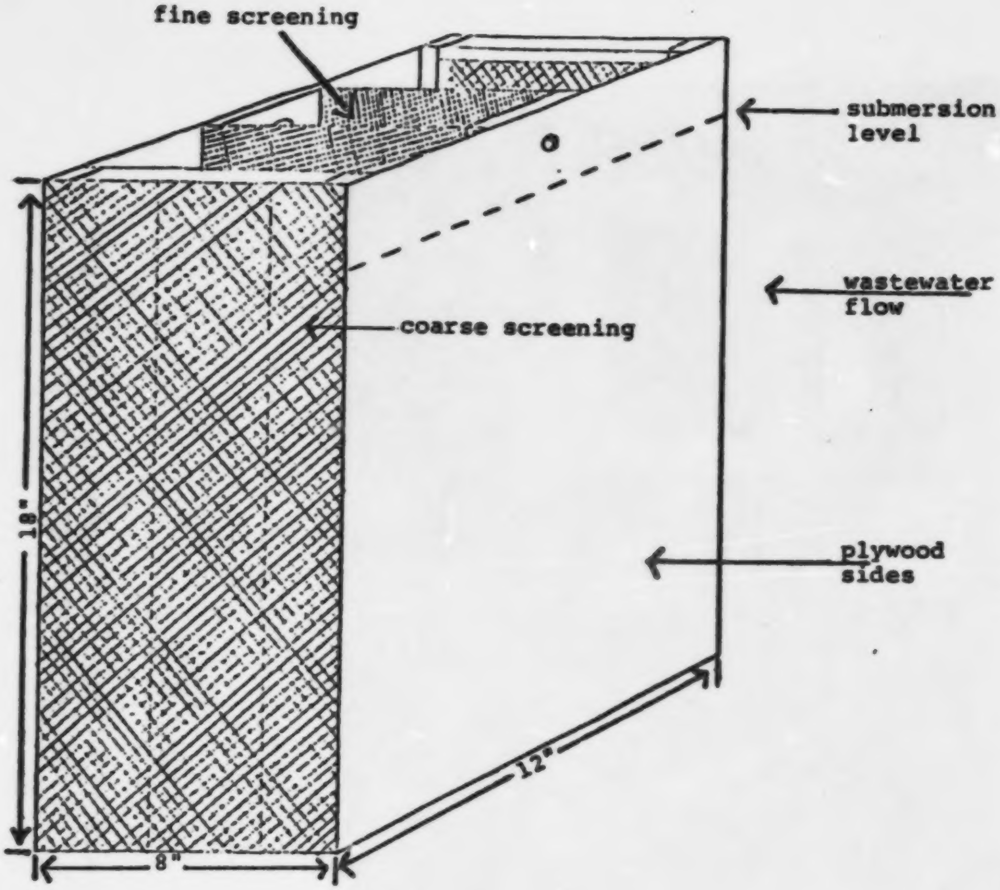


Figure 14: Close-up of BioMonitor at Wastewater Treatment Plant - Site 2


fine screening
submersion level
wastewater flow
coarse screening
plywood sides
18"
12"
8"

Frame: 2" x 2" and 2" x 4" construction
Suspended by ropes into wastewater to level indicated
Intake tubing suspended between section defined by fine screening
Entire screen stabilized in wastewater flow by 15 lb weight
attached to bottom

Figure 15. Modified screening device.

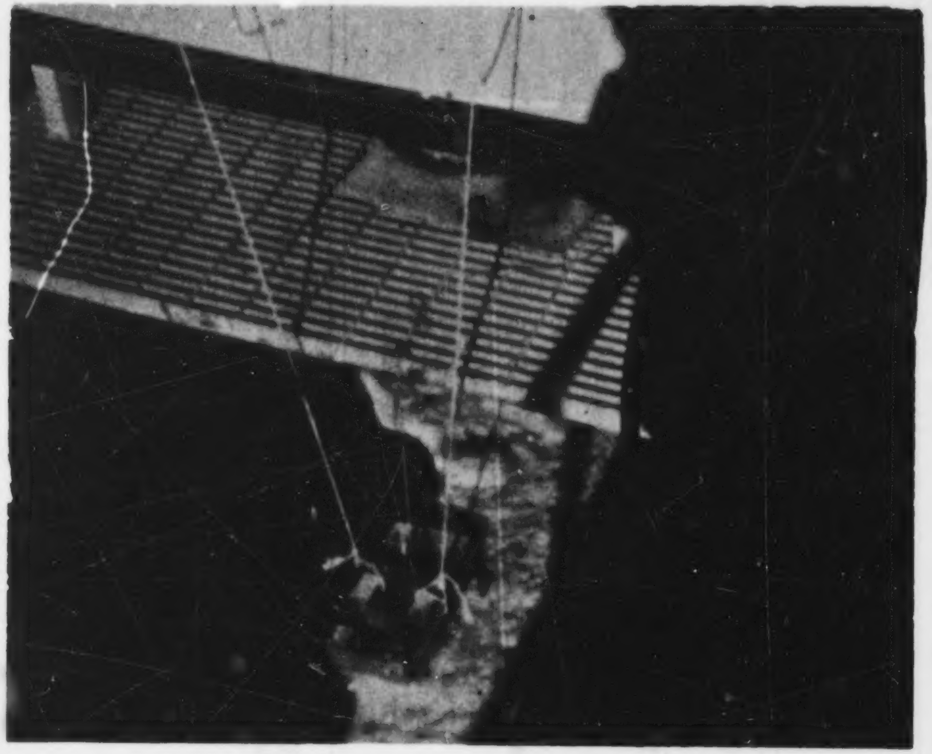


Figure 16. Photograph of Modified Screening Device

TABLE 15. DESIGN AND OPERATING PARAMETERS - WASTEWATER TREATMENT PLANT 2

Parameter	Design Value	Operating Value
Flow, MGD	25	7.8 - 9.5
Influent suspended solids, mg/l	300	88
% Removal	97	91
Influent BOD, mg/l	350	102
% Removal	97	95

TABLE 16. INDUSTRIAL SITE 2 - WASTEWATER CHARACTERISTICS*

Constituent	Concentration (mg/l)
BOD_5	23
Suspended Solids	69
Grease	24
Chromium	0.03
Copper	0.03
Zinc	0.45
Iron	82.5
Nickel	40.0

*Source - Metropolitan Government analysis for municipal sewer discharge.

A 3-day around-the-clock test period was conducted. Maintenance and sampling routines were identical to those described in Appendix D. Additional samples were taken at the industrial site for metal analysis. As indicated previously, it was not anticipated that under "normal operating" conditions this industrial waste source would identifiably impact the municipal site. However, this afforded the opportunity to study a problem very different from that created by the first industrial site. The heavy metal content of the waste was analyzed in an effort to correlate variations in DO with variations in the metal concentration. The metals investigated were iron, zinc, total chromium and copper. Tests were run for nickel. Trace amounts, less than 0.01 mg/l were detected. Similarly, tests for lead concentrations were less than 0.1 mg/l. All metals analyzed were run on the acidified aqueous samples using atomic absorption spectrophotometry with an acetylene/air flame.

Appendix F contains the graphical representation of the data amassed over this 3-day period. Again, corresponding DO and TOC curves are drawn on the same graph to facilitate the evaluation of correlation. The following conclusions can be drawn from the review of this data:

- The second WWTP was a larger treatment facility with more and varied contributing industries. The overlaying of DO and TOC curves show the BioMonitor picks up the overall trend in TOC variation very well. Since the system did exhibit sufficient sensitivity at site 1, it can be assumed that no significant shock occurred at WWTP 2 during the surveillance period. The larger the WWTP facility the more of an equalizing effect experienced.
- The heavy metals monitored exhibited similarly shaped curves, with the possible exception of copper. Zinc was the highest average concentration followed by iron. There was also a similarity between the shape of the metals' curves and the corresponding TOC curves.
- The corresponding DO and TOC curves at the industrial site do not present as dramatic a profile as obtained from site 1 tests. The biomass in the BioMonitor could have been continuously inhibited by various small slugs of metals, acids, and proprietary organics. Again, overall trends of TOC increase and DO decrease (and the reverse relationship) are exhibited.

Efforts to substantiate these assumptions were made. The BioMonitor was shock loaded with a high concentration of chromic acid. The system responded immediately. The resultant curve was smooth and showed a continuous increase in DO over an extended period.

REFERENCES

1. Green, M.B.; Willetts, D.G.; Bennett, M.; Crowther, R.F.; and Bourton, J., "Applications of Toxicity Testing to Sewage Treatment Processes," Water Poll. Control, 74, p. 40 (1975).

2. Patterson, J.W.; Brezonik, P.L.; and Putnam, H.D., "Sludge Activity Parameters and Their Application to Toxicity Measurements and Activated Sludge," Proceedings of the 24th Ind. Waste Conf., Purdue University, p. 127 (1969).

3. Jackson, S. and Brown, V.M., "Effects of Toxic Wastes on Treatment Processes and Watercourses," Water Poll. Control, 69, 292 (1970).

4. Delaney, L.H., "Detection of Industrial Wastes in Municipal Systems," Jour. Water Poll. Control Fed., 42, 645 (1970).

5. Cairns, J.; Sparks, R.E.; and Waller, W.T., "The Design of a Continuous Flow Biological Early Warning System for Industrial Use," Proceedings of the 27th Ind. Waste Conf., Purdue Univ., p. 242 (1972).

6. Advertising Circular, Polymetron, Division of Uster Corp., Bioomall, PA, 1976.

7. Sletten, O., and Burbank, N.C., "A Respirometric Screening Test for Toxic Substances," Proceedings of 27th Ind. Waste Conf., Purdue Univ., pp 24-32 (1972).

8. "Self Contained Sampling and Measurement System Features Respirometer," Water and Sewage Works, 121, 2, 53 (1974).

9. Official Gazette of the U.S. Patent Office, Vol. 910, #2, p. 463, Patent No. 3731522, May 8, 1973.

10. "Continuous Determination of the Toxicity of Water, Wastewater, and Other Liquids, Using Microorganisms," French Patent No. 2,228,407(1974).

11. U.S. Environmental Protection Agency, Office of Research and Development, "Optimizing a Petrochemical Waste Bio-oxidation System Through Automation," Environmental Protection Technology Series, EPA-660/2-75-021 (1975).

12. Arthur, R.M., "The On-Line Respirometer and Its Use in Operation Control to Save Energy and Reduce Cost," 49th Annual Conf., WPCF, Minneapolis, Minn. (Oct., 1976).

13. Blok, J., "Respirometric Measurements on Activated Sludge," Water Res., 8,11 (1974).

14. Blok, J., "Measurements of the Viable Biomass Concentration in Activated Sludge by Respirometric Techniques," Water Res., Vol. 10, pp 919-925 (1976).

15. Eckenfelder, W.W., Water Quality Engineering for Practicing Engineers, Barnes & noble, Inc., New York (1970).

16. Coackley, P., and O'Neill, J., "Sludge Activity and Full-Scale Plant Control," Water Poll. Control, 74, 404 (1975).

17. Weddle, C.L., and Jenkins, D., "The Viability and Activity of Activated Sludge," Water Res., 5, 621 (1971).

18. Genetelli, E.J., "DNA and Nitrogen Relationships in Bulking Activated Sludge," J. Water Poll. Cont. Fed., 39, R32-44 (1967).

19. Standard Methods for the Examination of Water and Wastewater, 13th Ed., Amer. Pub. Health Assn., Washington, D.C. (1971).

20. Arthur, R.M., and Hursta, W.N., "Short Term BOD Using the Automatic Respirometer," Proc. of the 23rd Ind. Waste Conf., Purdue Univ., 242 (1968).

21. Mancy, K.H., Instrumental Analysis for Water Pollution Control, Ann Arbor Science Pub. Inc., Ann Arbor, Michigan (1975).

22. Patterson, J.W.; Brezonik, P.L.; and Putnam, H.D., "Measurement and Significance of Adenosine Triphosphate in Activated Sludge," Environ. Sci. and Technol., 4, 569 (1970).

23. Brezonik, P.L., and Patterson, J.W., "Activated Sludge ATP: Effects of Environmental Stress," Jour. San. Eng. Div., Proc. Amer. Soc. Civil Engr., 97, SA6, 813 (1971).

24. Holm-Hansen, O., and Paerl, H.W., "The Applicability of ATP Determination for Estimation of Microbial Biomass and Metabolic Activity," Proc. IBP-UNESCO Symp. on Detritus and Its Role in Aquatic Ecosystems, Pallanza, Italy (May 23-27, 1972).

25. Chiu, S.Y.; Kao, I.C.; Erickson, L.W.; and Fan, L.T., "ATP Pools in Activated Sludge," J. Water Poll. Cont. Fed., 45, 1746-1758 (1973).

26. Upadhyaya, A.K., and Eckenfelder, W.W., Jr., "Biodegradable Fraction as an Activity Parameter of Activated Sludge," Water Res., 9, 691 (1975).

27. Lenhard, G.; Nourse, L.D., and Schwartz, H.M, "The Measurement of Dehydrogenase Activity of Activated Sludges," Proc. 2nd Int'l Conf. Water Poll. Res., Tokyo, Japan (1964).

28. Bucksteeg, W., "Determination of Sludge Activity: A Possibility of Controlling Activated Sludge Plants," Proc. 3rd Int'l Conf. Water Poll. Res., Munich, Germany (1966).

29. Ford, D.L.; Yang, J.T.; and Eckenfelder, W.W., Jr., "Dehydrogenase Enzyme as a Parameter of Activated Sludge Activities," Proc. of 21st Ind. Waste Conf., Purdue Univ., 534 (1966).

30. Ryssov-Nielsen,H., "Measurement of the Inhibition of Respiration in Activated Sludge by a Modified Determination of the TTC-Dehydrogenase Activity," Water Res., Vol. 9, pp 1179-1185 (1975).

31. Klapwijk, A.; Drent, J.; and Sternvoorden, J.H.A.M., "A Modified Procedure for the TTC-Dehydrogenase Test in Activated Sludge," Water Res., 8, 121 (1974).

32. Jones, P.H., and Prasad, D., "The Use of Tetrazolium Salts as a Measure of Sludge Activity," Journ. Water Poll. Control Fed., 41, R441 (1969).

33. Vaicum, L., and Eminovici, A., "The Effect of Trinitro-Phenol and γ-Hexachlorocyclohexane on the Biochemical Characteristics of Activated Sludge," Water Res., 8, 1007 (1974).

34. Sulzer, F., and Westgarth, W., "Continuous DO Recording in Activated Sludge," Water and Sew. Works, 109, 10, 376 (1962).

35. Albertson. O.E., and DiGregorio, D., "Biologically Mediated Inconsistancies in Aeration Equipment Performance," Jour. Water Poll. Control Fed., 47, 976 (1975).

36. Young, B.A., "Development and Evaluation of a Continuous Monitor for a Biological Wastewater Treatment System," Master's Thesis, Vanderbilt University, Nashville, Tennessee (1976).

37. Hartman, L., and Laubenburger, G., "Toxicity Measurements in Activated Sludge," Jour. San. Eng. Div., Proc. Amer. Soc. Civil Engr., 94, SA2, 247 (1968).

38. Gaudy, A.F., Jr., and Turner, B.C., "Effect of Air Flow Rate on Response of Activated Sludge to Qualitative Shock Loading," Proc. 17th Ind. Waste Conf., Purdue Univ., 136 (1962).

39. Arthur, R.M., "An Automated BOD Respirometer," Proc. 19th Ind. Waste Conf., Purdue Univ., 628 (1964).

40. Simpson, J.R., and Nellist, G.R., "Development and Use of a Large-Volume Automatic Respirometer," Waster Poll. Control, 69, 596 (1970).

41. Advertising Circular, Robertshaw Controls Co., Model 970, Richmond, VA (1974).

42. Eckenfelder, W.W., and Ford, D.L., Water Pollution Control, Pemberton Press (1970).

43. Kalinske, A.A., "Effect of Dissolved Oxygen and Substrate Concentration on the Uptake Rate of Microbial Suspensions," Jour. Water Poll. Control Fed., 43, 73 (1971).

44. Duggan, J.B., and Cleasby, J.L., "Effect of Variable Loading on Oxygen Uptake," JWPCF, Vol. 48, No. 3, pp 540-550 (1976).

APPENDIX A

DEVELOPMENT OF A CONTINUOUS RESPIROMETER

As discussed in Section 5, DO/oxygen uptake was the parameter selected for use in the biological simulation monitor. A preliminary system, a continuous oxygen uptake meter or continuous respirometer, was developed to test preliminary concepts and evaluate the rapidity and reliability of response. As reviewed in the introduction, several continuous and semi-continuous respirometers have been developed. Although some systems offer good sensitivity, other aspects render them unsuited for this project. Below is a description of the continuous respirometer developed for this work.

DESCRIPTION OF THE CONTINUOUS RESPIROMETER

The respirometer basically is a 10 liter plexiglas laboratory activated sludge unit with a one-liter (adjustable volume), air tight side car (see Figure A-1). A variable speed pump brings mixed liquor from the aeration basin to the side car. Retention time in the side car can be varied not only by changing the pump delivery rate but also by adjusting the volume of the side car. The 5-inch diameter plexiglas cylinder which constitutes the side car is outfitted with exit ports at the 1, 1.5, 2 and 2.5 liter levels. The side car is made air tight by a floating plexiglas disc cover. This disc is fitted with a DO probe which extends approximately 4 cm into the liquor. A probe continuously monitors the DO level in the side car. A magnetic stirrer, set to create minimal vortexing, maintains a completely mixed system in the side car. The overflow returns to the aeration basin by gravity through the selected port.

The feed enters directly into the activated sludge unit and is completely mixed. The aeration basin retention time can also be varied. Similarly, the MLVSS, DO and temperature can be controlled to the desired conditions. The laboratory operating parameters are listed in Table A-1.

After testing various aeration devices, we selected a commercially available aerator sold to aerate fish tanks and aquaria. It is a permanent (cf air stones) hollow tube of plastic material which is porous throughout its length.*

*"Bubble Wand," Marine and Aquarium Products, Division of Aquaria, Inc. 15800 Armenta Street, Van Nuys, California 91406.

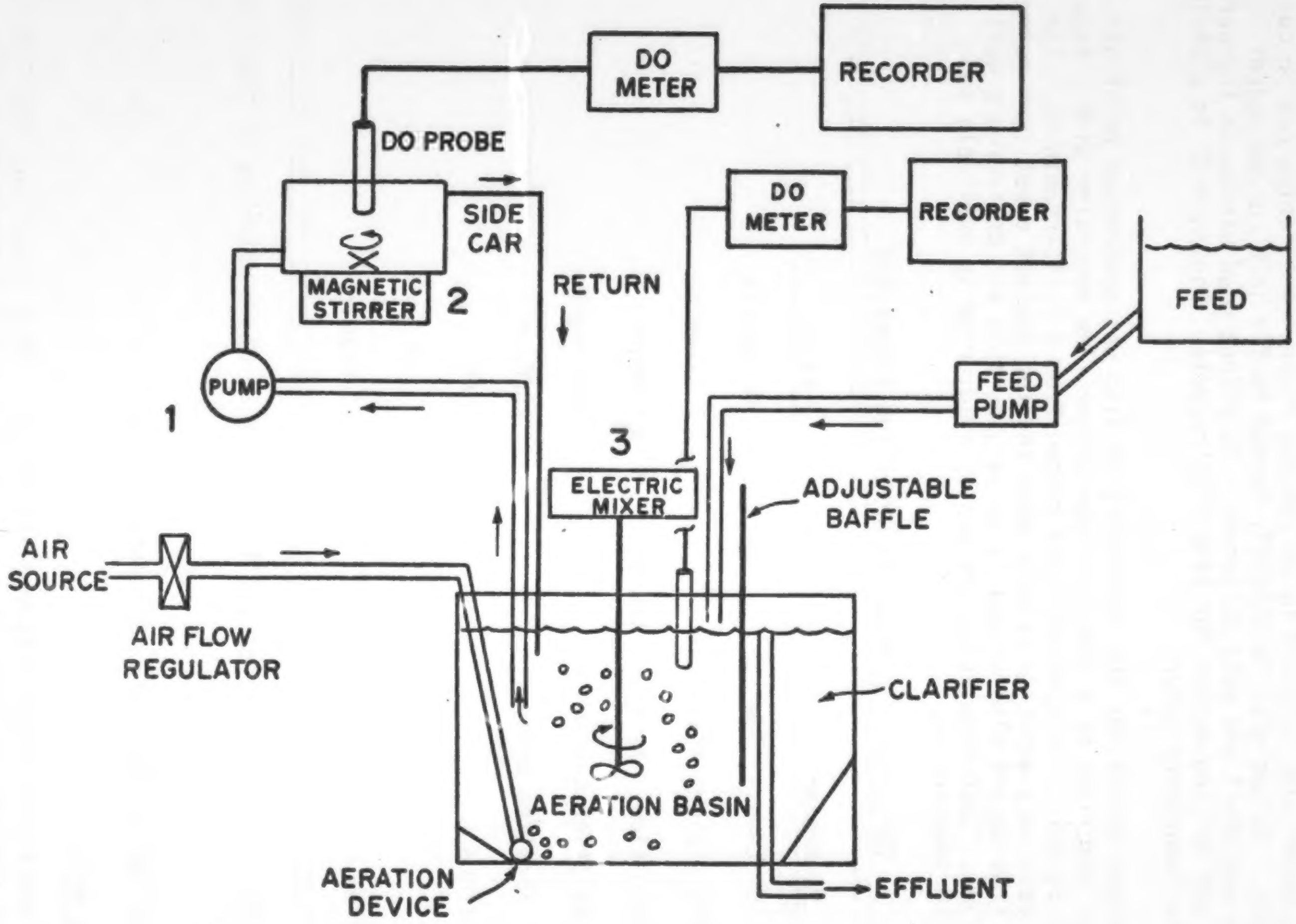

DO METER
RECORDER
DO PROBE
SIDE CAR
MAGNETIC STIRRER
2
RETURN
DO METER
RECORDER
FEED
PUMP
1
FEED PUMP
3
ELECTRIC MIXER
ADJUSTABLE BAFFLE
AIR SOURCE
AIR FLOW REGULATOR
CLARIFIER
AERATION BASIN
AERATION DEVICE
EFFLUENT

Figure A-1. Schematic of the continuous respirometer.

It did not exhibit the tendency towards rapid clogging as did sintered glass spargers. The sintered glass also was difficult to clean. The tubing is readily available, inexpensive and therefore disposable. However, the tubing can be readily cleaned and reused. The tubing is cleaned by scraping the surface with a razor edge followed by an aqueous rinse. The tubing can be cut to any length. It can also be slightly formed to fit into curved spaces. Bubble size was small and well patterned - to effect good mixing in the aeration basin and rolling action for clarifier recycle. Figure A- 2 is a photograph of the laboratory setup.

The oxygen source for the laboratory studies was compressed house air. The flow was regulated by a hospital-type oxygen flow regulator with a back pressure of 50 psi. The type employed ranged from 0-7 liters/minute. The regulators gave very accurate results when checked against a wet test meter. The oxygen flow meters also proved to be very durable and delivered a well regulated flow. Such regulators are easily read, readily available and comparatively inexpensive.

TABLE A-1. LABORATORY OPERATING PARAMETERS

Parameter	Value
Retention time - side car	10 minutes
Retention volume -side car	1 liter
Retention time - aeration basin	6 hours
MLSS, aeration basin	3000 mg/l
MLVSS, aeration basin	2500 mg/l
Temperature	20°C
pH	5 - 7
Feed flow	15 ml/min

The pumps employed were either laboratory solution metering or positive displacement.

CHARACTERIZATION OF THE CONTINUOUS RESPIROMETER

Preliminary Work

Three continuous respirometers were set up. In a 5-day run, the F/M ratio of the feed varied every 24 hours in units 1 and 3 according to the pattern:

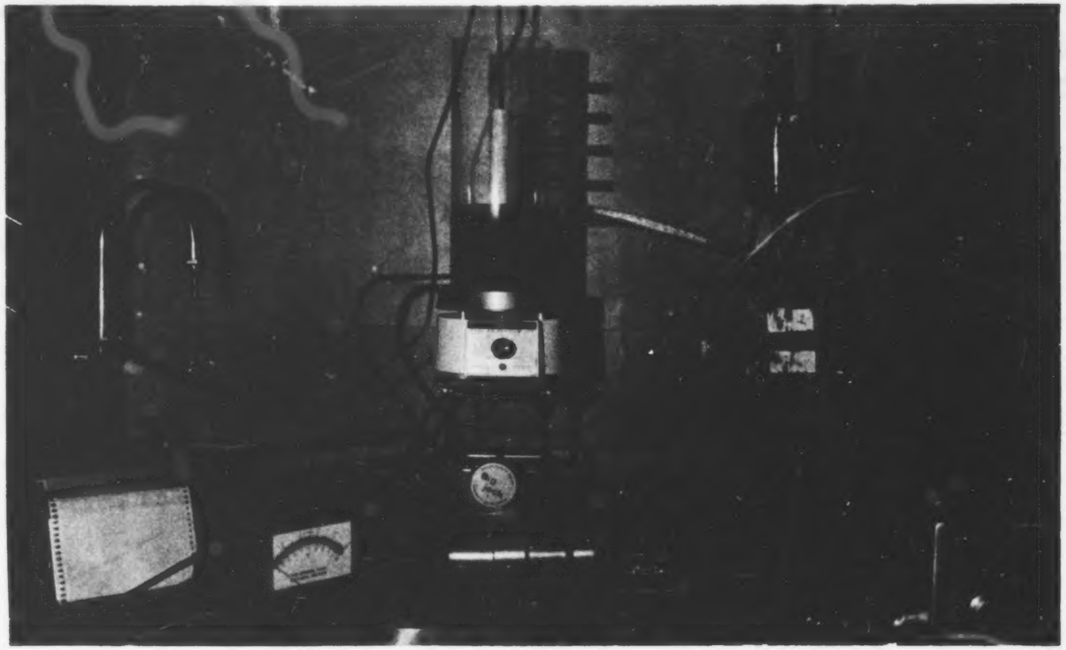


Figure A-2. Photograph of Continuous Respirometer

Day	1	2	3	4	5
F/M	0.3 →	0.6 →	0.3 →	0.1 →	0.3

(This 5-day test was repeated the following week.) F/M is the "food-to-microorganism" ratio. It is defined mathematically as follows in Equation (A-1):

$$F/M = 24\ S_o/t\ X_v \qquad \text{(A-1)}$$

where:

S_o is the BOD concentration of the feed (substrate) in mg/l

t is the retention time in hours

X_v is the concentration of biomass (MLVSS) in mg/l.

The factor of 24 (hours/day) converts hours into days so that F/M has units of inverse days.

F/M change was effected by varying the concentration of commercial powdered evaporated skim milk and dibasic ammonium phosphate $(NH_4)_2\ HPO_4$ (as an an additional nitrogen and phosphorus source). The operating parameters employed are given in the previous section. The DO levels in the side-car and basins were continuously monitored and recorded. The F/M ratio was maintained in unit 2 at 0.3 throughout the 5-day run as a control.

The DO levels in both the aeration basins and side cars varied noticeably within the first 60 minutes of the F/M change. As expected with healthy biological systems the DO increased when the F/M ratio decreased and decreased when this ratio increased. A comparison of the sensitivity, i.e., rate of change of DO in the side car and in the aeration basin, was made. Preliminary results indicated that changes in the side car DO level averaged 1 1/2 to 2 times more sensitive to changes in F/M during the first 60 minutes than the DO level changes in the aeration basins. This was substantiated by 21 additional short-term runs where the F/M value in influent varied approximately every two hours. The sensitivities were evaluated according to Equation (A-2). The time, t_i, was evaluated from 0 through 60 minutes at 5 minute intervals.

$$S = (d[O_2]/dt)_{t_i},\ \text{side car} \Big/ (d[O_2]/dt)_{t_i},\ \text{aeration basin} \qquad \text{(A-2)}$$

The rate of change in DO was obtained by curve fitting the strip chart graph (0-60 minutes) to a second order polynomial using a least squares analysis. Correlation coefficients for the resulting equation were greater than 0.9800. See Figure A-3 for representative curves of DO versus time for the aeration basin and side car.

The DO meters and probes were YSI of Ohio instruments.

In this preliminary work additional parameters were run in an effort to

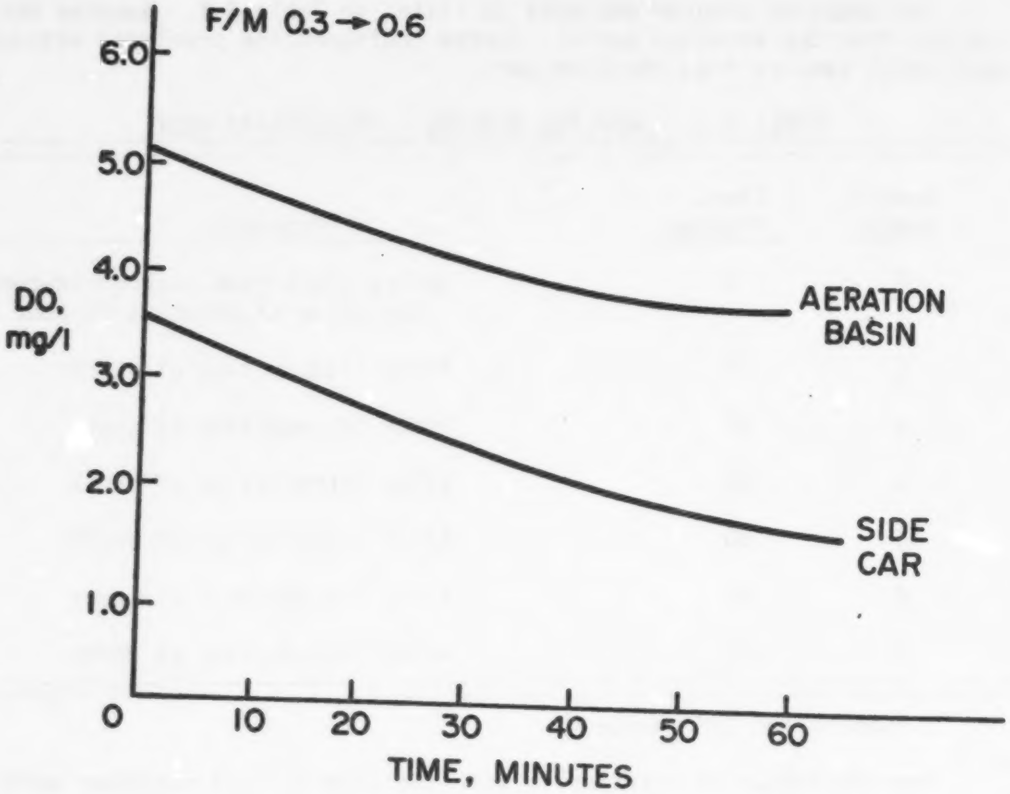


Figure A-3. Representative curves - DO vs time - preliminary study.

corroborate the results obtained from the continuous respirometer. These analyses included: triphenyltetrazolium chloride (TTC); total organic carbon (TOC); and adenosine triphosphate (ATP)(blended samples). The TOC was run according to Standard Methods (A-1) using acidification to eliminate inorganic carbon. The TTC analysis was performed according to the test procedure proposed by Lenhard et al. (A-2) and modified by Ford et al. (A-3). The ATP analysis was performed according to the modified test procedure of Upadhyaya (A-4).

The sampling program employed is listed in Table A-2. Samples were grab samples from the aeration basin. System configuration precluded obtaining meaningful samples from the side car.

TABLE A-2. SAMPLING ROUTING - PRELIMINARY WORK

Sample Number	Time, Minutes	Comments
1	0	Before shock* was introduced-represented value of previous 24-hour period
2	15	After introduction of shock
3	30	After introduction of shock
4	45	After introduction of shock
5	60	After introduction of shock
6	90	After introduction of shock
7	120	After introduction of shock

*Controlled F/M change.

The continuous DO readings in both the side car and aeration basin exhibited the correct changes for the variations in the feed. The sampling did not interfere with these readings.

Results of TTC Analyses--

The curves resulting from the daily analysis of the seven samples exhibited similar but inconclusive behavior. Approximately forty-five to sixty minutes after the shock was introduced a decrease in TTC was noted. This occurred whether the F/M ratio was increased or decreased. Overall curve shapes are similar. Figure A-4 shows representative TTC curves. By the seventh sample, two hours after introduction of the shock, the TTC value is approaching its initial value.

There was a correlation between the TTC value obtained from sample 1 (t = 0) and the ambient, steady state F/M level. See Table A-3 for the results.

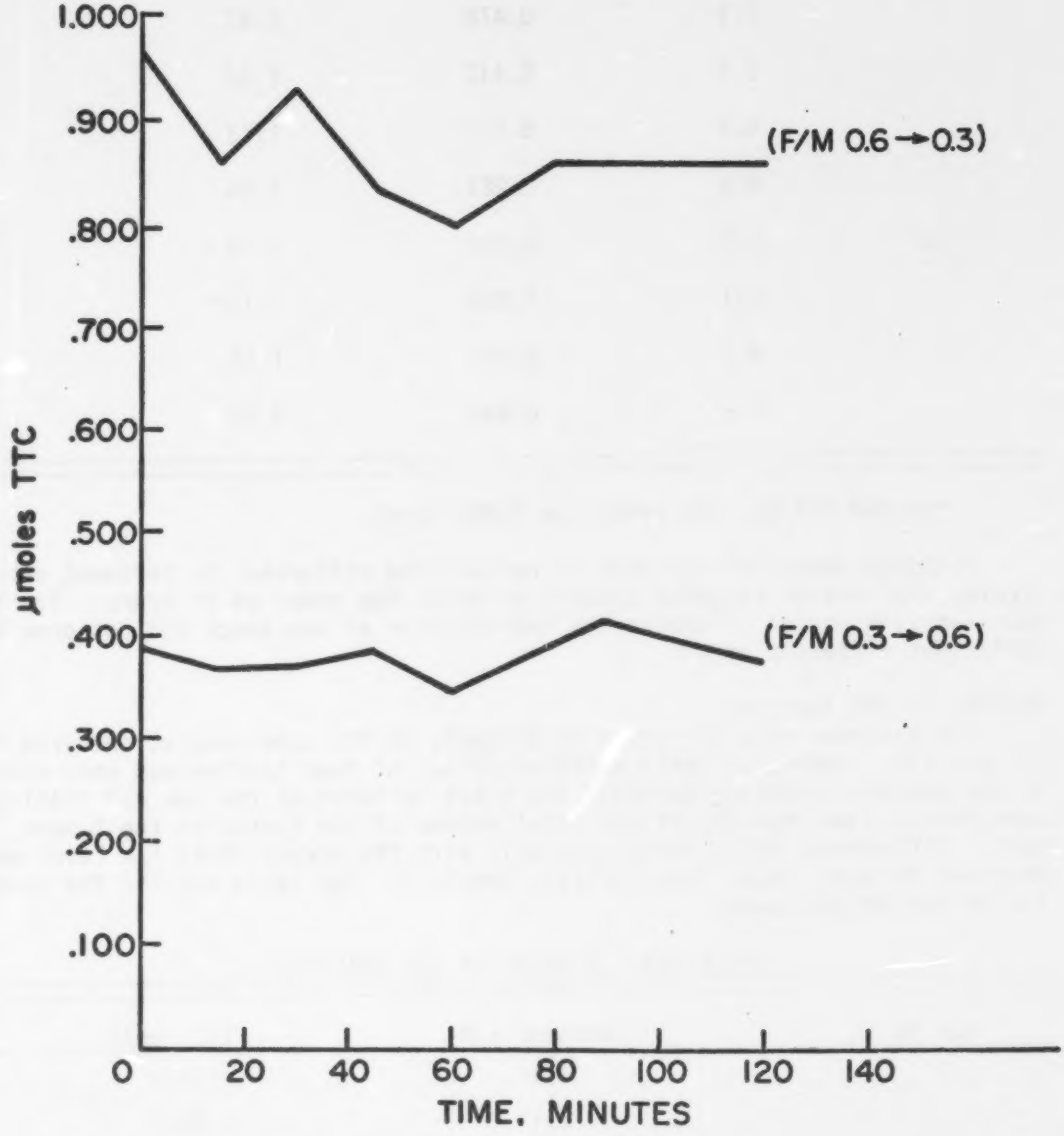


Figure A-4. Representative TTC curves.

TABLE A-3. RESULTS OF TTC ANALYSES

Run No.	Ambient F/M	TTC, μ moles	(TTC, μ moles/ mg/l MLVSS x 10^4)
I	0.3	0.478	1.42
	0.1	0.442	1.48
	0.3	0.531	1.73
	0.6	0.961	2.94
II	0.3	0.362	1.10
	0.1	0.304	1.15*
	0.3	0.391	1.45
	0.6	0.846	3.00

*Wasted solids, 20% reduction MLVSS level.

Although these TTC analyses do reflect the difference in influent substrate, the time of response appears to be on the order of 24 hours. The two-hour sampling period following the introduction of the shock did not provide sufficient differentiation.

Results of TOC Analyses--

TOC analyses were performed on aliquots of the same samples analyzed for TTC and ATP. Again, no early differentiation of feed loading was seen within the two-hour sampling period. The total influent at the new F/M loading contributed a maximum 10% of the total volume of the system at the 2-hour mark. Differences which correlated well with the steady state F/M level were obtained 24 hours later from analysis sample 1. See Table A-4 for the results of the TOC analyses.

TABLE A-4. RESULTS OF TOC ANALYSES

Run No.	Ambient F/M	TOC, mg/l
I	0.3	77.3
	0.1	58.7
	0.3	63.0
	0.6	80.6
II	0.3	68.1
	0.1	60.4

(continued)

TABLE A-4 (continued)

	0.3	--
	0.6	71.2

Results of ATP Analyses--

A third aliquot of the samples was analyzed for changes in ATP content. Procedural problems precluded any meaningful data being obtained from this analysis. In consideration of the conclusions of the literature review of ATP, no additional effort was made to repeat the 5-day runs to obtain meaningful ATP data.

At this juncture it was concluded that the continuous respirometer equipped with DO probes provided a rapid and predictable indicator of microorganism activity. The next step was to specifically characterize the system's response and reproducibility. This is discussed in detail in the next section.

Characterization Study

The following experiment was designed to obtain the quantifying information on the continuous respirometer:

- Simultaneous data was obtained from both the side car and the aeration basin.
- All runs were performed at least twice.
- The system was in a steady state at F/M = 0.3. The steady state was evidenced by monitoring a steady DO level (≤ 0.02 mg/l average DO variation in a 12 minute period). Ambient DO levels were maintained as similar as possible between systems and within the same system from day to day.
- A shock, changing the F/M, was applied for one hour and the resulting change in DO was monitored continuously.
- The system was returned to an F/M of 0.3 and continuously monitored for one hour.
- A reading was taken two hours after the 0.3 F/M feed was reapplied.
- A period of not less than two additional hours was provided at an F/M of 0.3 for system stabilization.
- A second run at a different F/M shock was then performed in a similar manner. F/M levels used were 0.1, 0.2, 0.3, 0.4 and 0.5
- Simultaneously (and analogously) two other BioMonitor systems were run at steady state F/M's of 0.1 and 0.5. Their responses to the shock loads were monitored.

This experiment was designed to determine the reproducibility of the systemic change to a repeated shock loading; correlation of response to shock size; return to pre-shock stability after shock removal; and overall reliability. Chemical oxygen demand (COD) analyses were performed along with the DO monitoring. The COD tests were run according to Standard Methods (19).

TABLE A-5. RESULTS OF INTER-SYSTEMS COMPARISONS

	Aeration Basin			Side Car		
Baseline F/M	0.1	0.3	0.5	0.1	0.3	0.5
Average change in DO ($\Delta DO/\Delta T$, mg/l/hr) for 0.1 change in F/M	0.54	0.37	0.16	0.68	0.49	0.12
Average change in DO per conc., MLVSS ($\Delta DO/\Delta T$/MLVSS, mg/l/hr/MLVSS/mg/l) for 0.1 change in F/M x 10^4	3.0	2.3	0.6	3.9	3.1	0.4
Average time to notice a change of DO of 1.0 mg/l in minutes	3.8	5.4	7.6	3.7	7.7	7.9
Average % return to original DO level 2 hours after removal of shock	96	95	96	87	90	79
Average absolute value of difference from DO level 2 hours after removal of shock, mg/l	0.2	0.4	0.2	0.4	0.2	0.1

TABLE A-6. CORRELATION COEFFICIENTS

Function	Correlation Coefficients for 1st order fit
$\Delta DO/\Delta t$, mg/l/hr vs Δ F/M units	
Aeration Basin	0.989
Side Car	0.995
$\Delta DO/\Delta t$, mg/l/hr/mg/l MLVSS vs $\Delta F/M$ units	
Aeration Basin	0.992
Side Car	0.995

TABLE A-7. RESULTS FROM COD EXPERIMENTS*

Run	I	II	III	IV	V	VI	VII	VIII	IX
F/M Change	0.1→0.3	0.3→0.1	0.5→0.3	0.1→0.2	0.3→0.2	0.5→0.2	0.1→0.2	0.3→0.2	0.5→0.2
Before AM Shock	2117	2422	3457	2064	2377	3596	2518	2346	2912
After AM Shock	2510	2520	3273	2198	2319	3428	2408	2541	3036
End of AM Run	2448	2492	3572	2058	2354	3362	2586	2071	3256
F/M Change	0.1→0.5	0.3→0.5	0.5→0.1	0.1→0.4	0.3→0.4	0.5→0.4	0.1→0.4	0.3→0.4	0.5→0.4
Before PM Shock	2462	2206	3354	2396	2289	3188	2235	2230	3126
After PM Shock	2266	2794	3244	2266	2106	3134	2228	2142	2888
End of PM Run	2388	2358	3076	2325	2144	3057	2202	1958	2758

*results reported as mg/l COD

TABLE A-8. RESULTS FROM COD EXPERIMENT - MINUS FEED*

Run	I	II	III	IV	V	VI	VII	VIII	IX
F/M Change	0.1→0.3	0.3→0.1	0.5→0.3	0.1→0.2	0.3→0.2	0.5→0.2	0.1→0.2	0.3→0.2	0.5→0.2
Before AM Shock	1977	2099	2909	1962	2043	3044	2411	2025	2373
After AM Shock	2370	2217	2700	2084	1996	2913	2290	2233	2527
End of AM Run	2308	2189	3046	1946	2030	2843	2469	1747	2744
F/M Change	0.1→0.5	0.3→0.5	0.5→0.1	0.1→0.4	0.3→0.4	0.5→0.4	0.1→0.4	0.3→0.4	0.5→0.4
Before PM Shock	2342	1883	2806	2294	1955	2636	2128	1909	2587
After PM Shock	2099	2446	2743	2130	1764	2598	2088	1811	2361
End of PM Run	2226	2055	2570	2193	1803	2519	2066	1620	2230

*results reported as mg/l COD

The results of these experiments are listed in Tables A-5, A-6, A-7, and A-8 and Figures A-5 thru A-8. The following summarizations and conclusions can be made:

(a) There is more sensitivity (larger ΔDO) to a change in F/M loading in both the side car and aeration basin for the system at the steady state F/M of 0.1; the least sensitivity at 0.5 F/M.

(b) The system operated at a steady state F/M = 0.1 results in a linear relationship (in the range studied) for ΔDO (mg/l) versus F/M and for ΔDO [mg/l/hr)/(mg/l MLVSS)] in both the side car and the aeration basin data. The correlation coefficient of the corresponding first order polynomials are given in Table A-6.

(c) The system operated at a steady state F/M of 0.1 also yields, on the average, the most rapid response in both the side car and aeration basin compared to the systems operating at steady state F/M's of 0.5 and 0.3. There appears to be no significant correlation between average response time and magnitude of F/M change for any of the three cases.

(d) In the aeration basin, the percent return to original DO level, that is prior to F/M shock, is 95% or better in all three cases after two hours. The average percent return in the side car of 86% after two hours reflects the comparatively low levels of ambient DO. The DO level in the side car returned to within an average of 0.2 mg/l off its original DO value.

(e) The results of the COD experiment are seen in Tables A-7 and A-8. Table A-7 lists the COD values determined from the aeration basin samples. Table A-8 lists the COD values less the appropriate, weighted feed value. The feed value is a function of F/M level in the aeration basin and shock feed and the percent volume of shock added in two hours. Neither set of data provides a predictable pattern. This is due, in part, to the problems of obtaining a truly homogeneous sample from the mixed liquor for analysis. Another aspect of the COD analysis is that the changes are too rapid to elicit any significant (measurable) response within the organism. Moreover, the magnitude of the changes is small. The experiment yielded an average BOD/COD ratio of 0.77 for the powdered skim milk used. The average ratio of mg MLVSS/mg COD for the mixed liquor was 0.875 before shocking.

This information characterizes the continuous respirometer system. The increased sensitivity and rapidity of response at the lowest level F/M investigated is easily explained: The impact of addition or removal of substrate at the lower feed level is greater because any change represents a larger percent variation from the steady state. The microorganisms are so well fed at an F/M = 0.5, that a short change in feed (addition or removal) has little effect. It is especially evident when comparing ΔDO/Δt's between steady state F/M's of 0.1 and 0.5 (Table A-5). It should be noted, however, that at a steady state F/M of 0.1, the MLVSS cannot be maintained at a 2500 mg/l level. They do stabilize fairly well at slightly less than 2000 mg/l.

At this point actual industrial wastes were brought to the laboratory and applied to the continuous respirometers. The details are given in the next section.

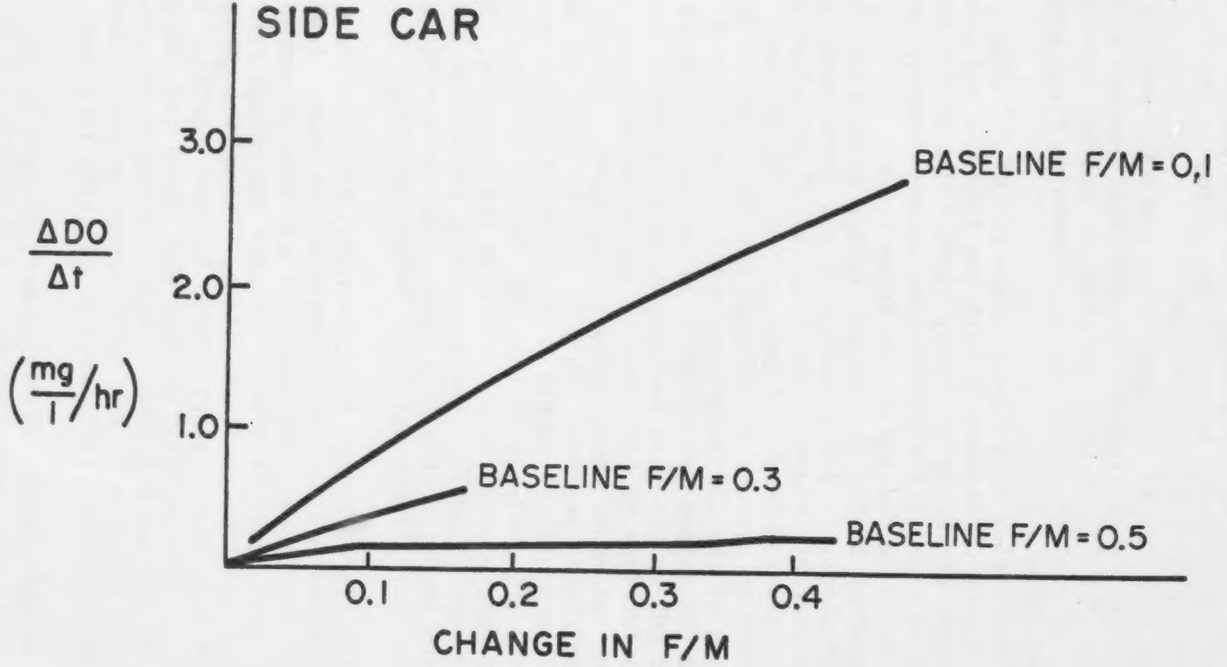


Figure A-5. F/M change vs $\Delta DO/\Delta t$ (mg/1-DO/hr) - side car.

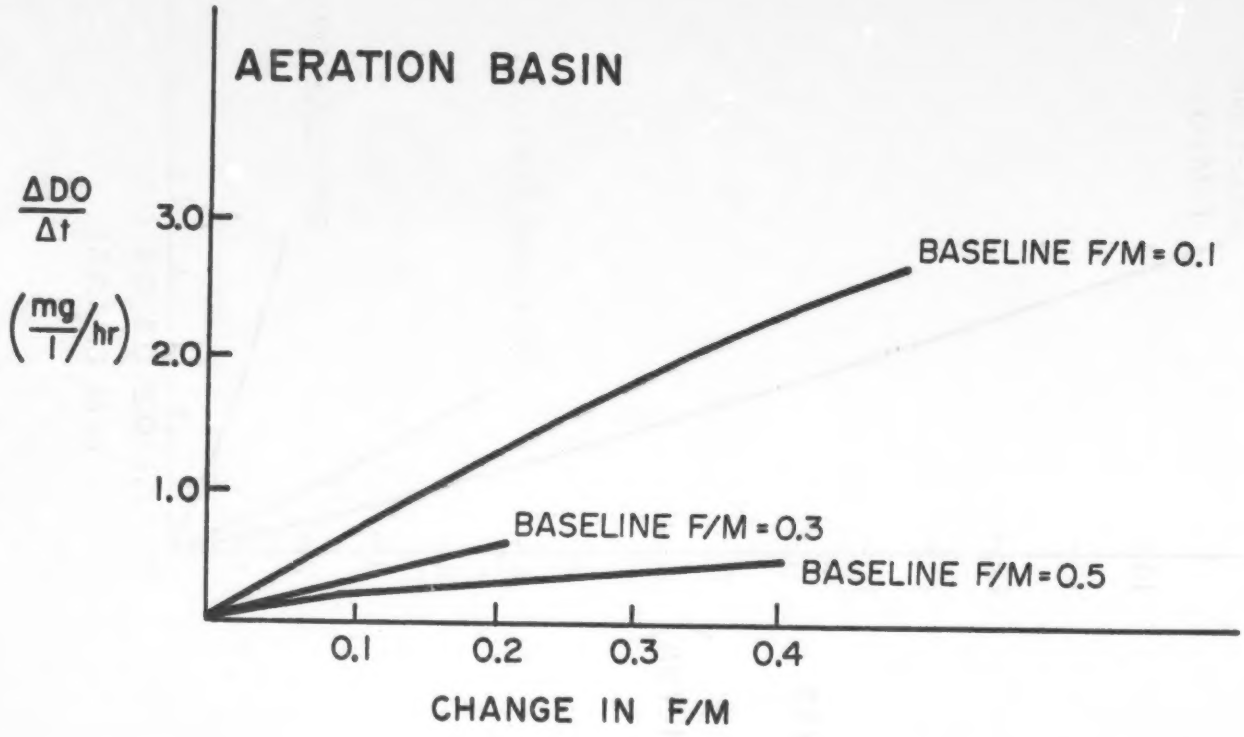


Figure A-6. F/M change vs ΔDO/Δt (mg/1-DO/hr) - aeration basin.

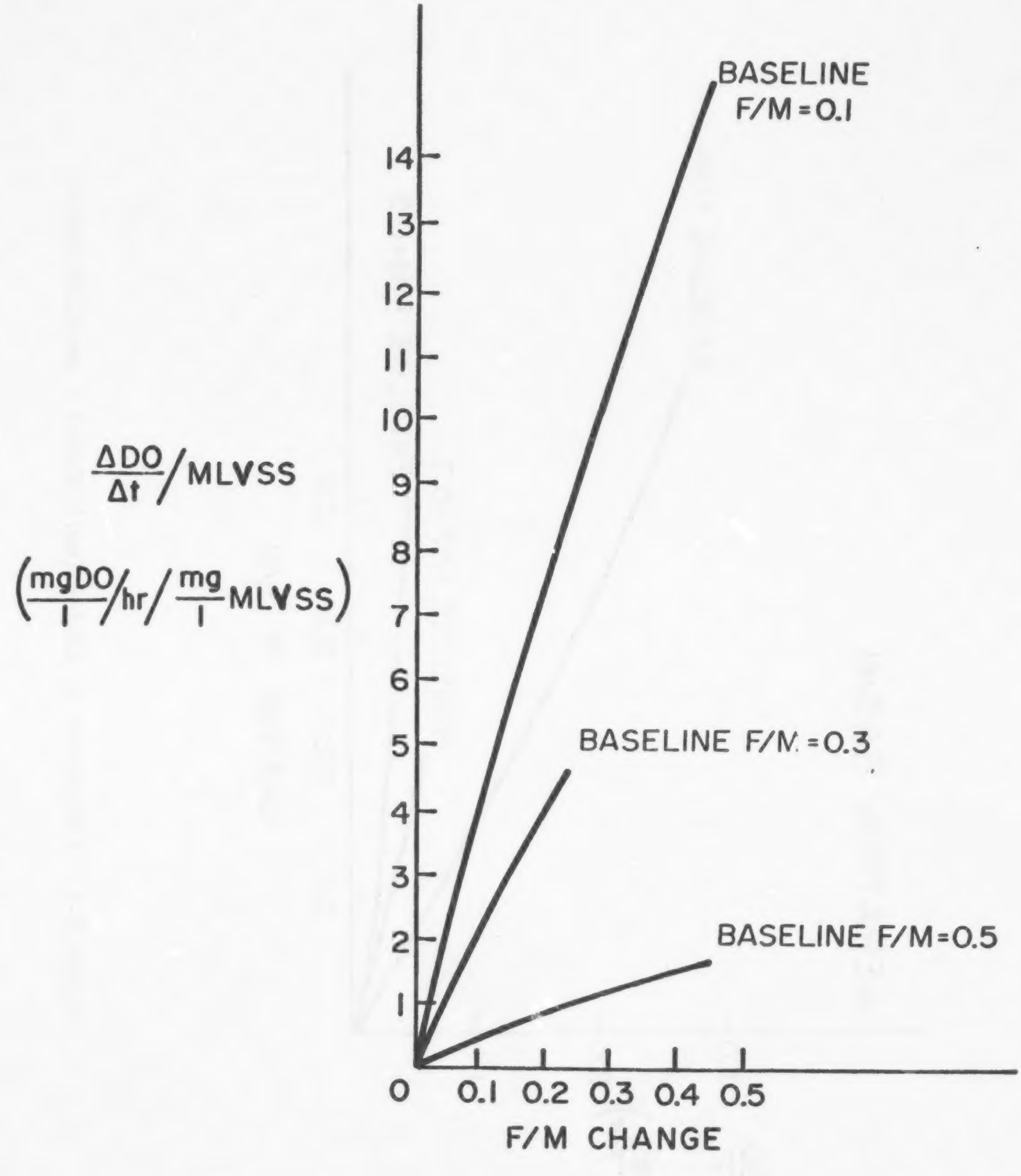


Figure A-7. F/M change vs ΔDO/Δt per MLVSS (mg/l-DO/hr/mg/l-MLVSS) - side car.

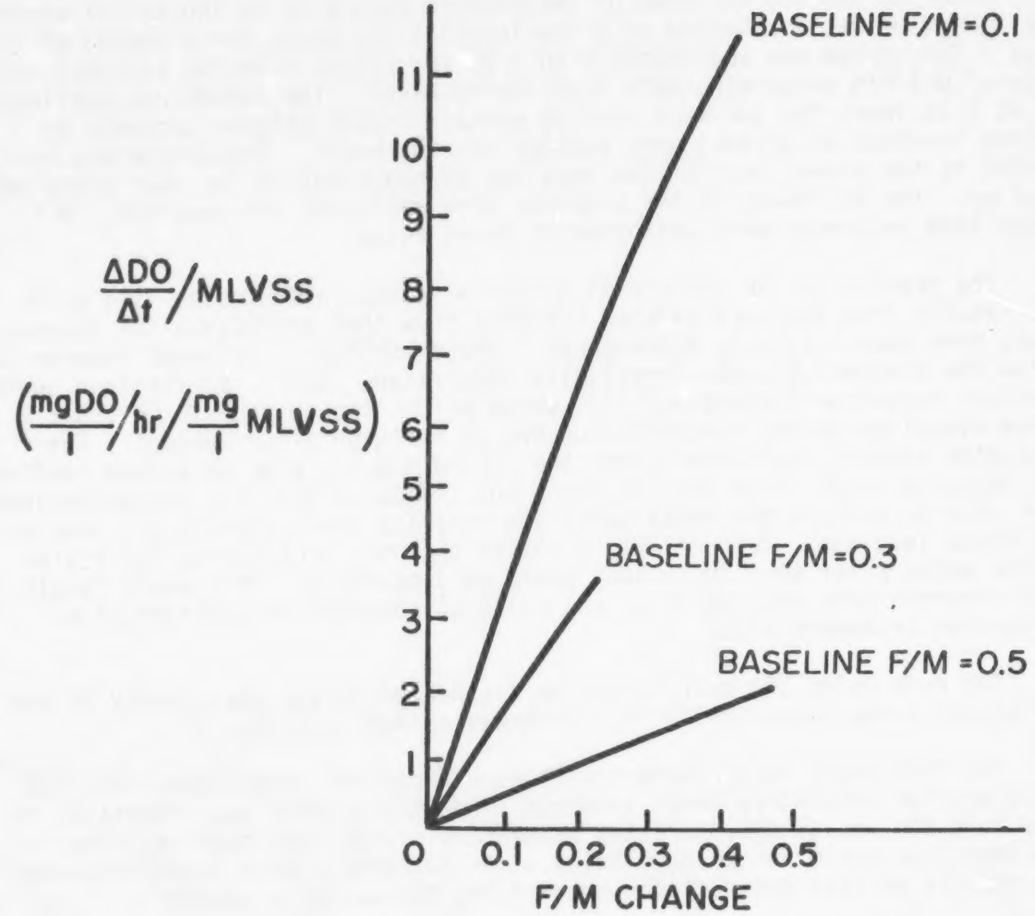


Figure A-8. F/M change vs ΔDO/Δt per MLVSS (mg/l-DO/hr/mg/l-MLVSS) - aeration basin.

Industrial Wastes Study

Samples of two industrial wastes were tested in the laboratory - a dairy waste and a meat packing waste. The former recycles whey for use in pig farming while the latter does not retrieve the blood and fat for reuse in feeds and tallow, etc. The dairy waste has a BOD of approximately 1200 mg/l with a TSS of 300 mg/l. The meat packing waste has a BOD of approximately 900 mg/l.

Prior to the shockloading of the respirometer with an industrial waste, the biosystem was acclimated to a low level of the waste for a period of five days. The system was acclimated with a 3% (by volume with the standard solution of 0.3 F/M evaporated milk feed) dairy waste. The system was acclimated at a 1% level for the meat packing waste. Shocks (higher percents by volume loadings of wastes) were applied for two hours. The system was returned to the proper acclimation feed for 22 hours before the next shock was applied. The DO levels in the side car were monitored and recorded. All shock load sequences were performed at least twice.

The results of the industrial shocks are seen in Tables A-9 and A-10. The results from the meat packing industry show that inhibition (DO increase) could have been initially experienced. The variation in DO level however is below the Winkler/DO probe sensitivity comparison. The 1% acclimation period does not appear sufficient for this waste which, though high in BOD, has a large dissolved solids concentration due to the high blood content. The biosystem appears acclimated after the second shock - a 5% by volume loading. The decrease in DO (from the 10% shock on) indicates that the microorganisms were able to utilize the waste substrate entering the system in the remaining shock loadings. This result suggests that not acclimating the system to the waste prior to a shock load would be preferable. This would result in a response more indicative of the response observed on location at a wastewater treatment plant.

The runs using the dairy waste as a shock performed analogously to the F/M shocks using evaporated milk. This was as anticipated.

The continuous respirometer provides a rapid and predictable response to controlled laboratory shock loadings. Additional work was undertaken to fine tune the design and operating parameters of the respirometer. Special consideration was given to developing a monitor with a more rapid response. The results of this modification program are discussed in Section 6.

TABLE A-9. RESULTS OF MEAT PACKING INDUSTRIAL WASTES RUN - SIDE CAR DATA*

Percent Shock, conc. by vol.	ΔDO, mg/l O_2, @ 16 min.
3	+ 0.10
5	+ 0.09
10	- 0.04
20	- 0.08
33 1/3	- 0.30

*acclimation @ 1%

TABLE A-10. RESULTS OF DAIRY INDUSTRIAL WASTES RUN - SIDE CAR DATA*

Percent Shock, conc. by vol.	ΔDO, mg/l O_2, @ 16 min.
10	- 1.08
20	- 1.19
33 1/3	- 2.29
50	- 3.36

*acclimation @ 3%

REFERENCES

1. "Standard Methods for the Examination of Water and Wastewater," 13th Edition, Amer. Public Health Assn., Washington, D.C. (1971).

2. Lenhard, G.; Nourse, L.D.; and Schwartz, H.M. "The Measurement of Dehydrogenase Activity of Activated Sludges," Proc. 2nd Int'l Conf. Water Poll. Res., Tokyo, Japan (1964).

3. Ford, D.L.; Yang, J.T.; and Eckenfelder, W.W. "Dehydrogenase Enzyme as a Parameter of Activated Sludge Activities," Proc., 21st Ind. Waste Conf., Purdue University, West Lafayette, Indiana (1966).

4. Upadhyaya, A.K., "Determination of Relationships Between Biodegradable Fraction and Viable Mass in Activated Sludge Systems and Their Significance in Design," Ph.D. Dissertation, Vanderbilt University, Nashville, Tennessee (1973).

APPENDIX B

DEVELOPMENT OF PROPOSED MATHEMATICAL MODELS FOR BIOMONITOR RESPONSE

In general, the literature indicates that a lag in the response of specific growth rate to changes in influent flow rate and substrate concentration exists (B-1-B-3). The Monod model (B-4) is unable to predict the dynamic behavior of microbial growth subject to the changes in dilution rate and influent substrate concentration. More complicated models accounting for physiological state of microorganisms are necessary to achieve even qualitative agreement of model with experimental data.

BASIC CONCEPTS OF MICROBIAL GROWTH

In aerobic biological waste treatment systems, the influent organic substrate is contacted with activated sludge of the mixed liquor in aeration basins. The activated sludge reacts biochemically with the organic matter, converting it to carbon dioxide, water, and additional sludge mass. Equation (B-1) depicts the reaction and is the basis for the model developed in this study.

$$\text{Soluble Substrate} + O_2 \xrightarrow{\text{Microorganisms}} \begin{array}{l}\text{Active Cells}\\ \text{Nonactive Cells}\\ \text{Biodegradable Residue}\\ \text{Nonbiodegradable Residue}\\ CO_2\\ H_2O\end{array} \qquad \text{(B-1)}$$

A serial conversion of soluble substrate to active mass and nonactive mass, as depicted in Figure B-1, will be assumed. Total organic carbon (soluble) concentrations in influent and effluent will be measured as organic substrate and volatile suspended solids of mixed liquor as biomass concentration.

The basic relationships between the specific growth rate of microorganisms and the concentration of soluble substrate are discussed below.

A variety of mathematical models have been proposed to describe the basic kinetics of microbial growth and substrate removal in the activated sludge system. In 1942, Monod (B-4) proposed a kinetic model of microbial growth in pure culture which depends on the cell and substrate concentrations. The growth rate of microorganisms may be expressed as follows:

$$dX/dt = \mu X \qquad \text{(B-2)}$$

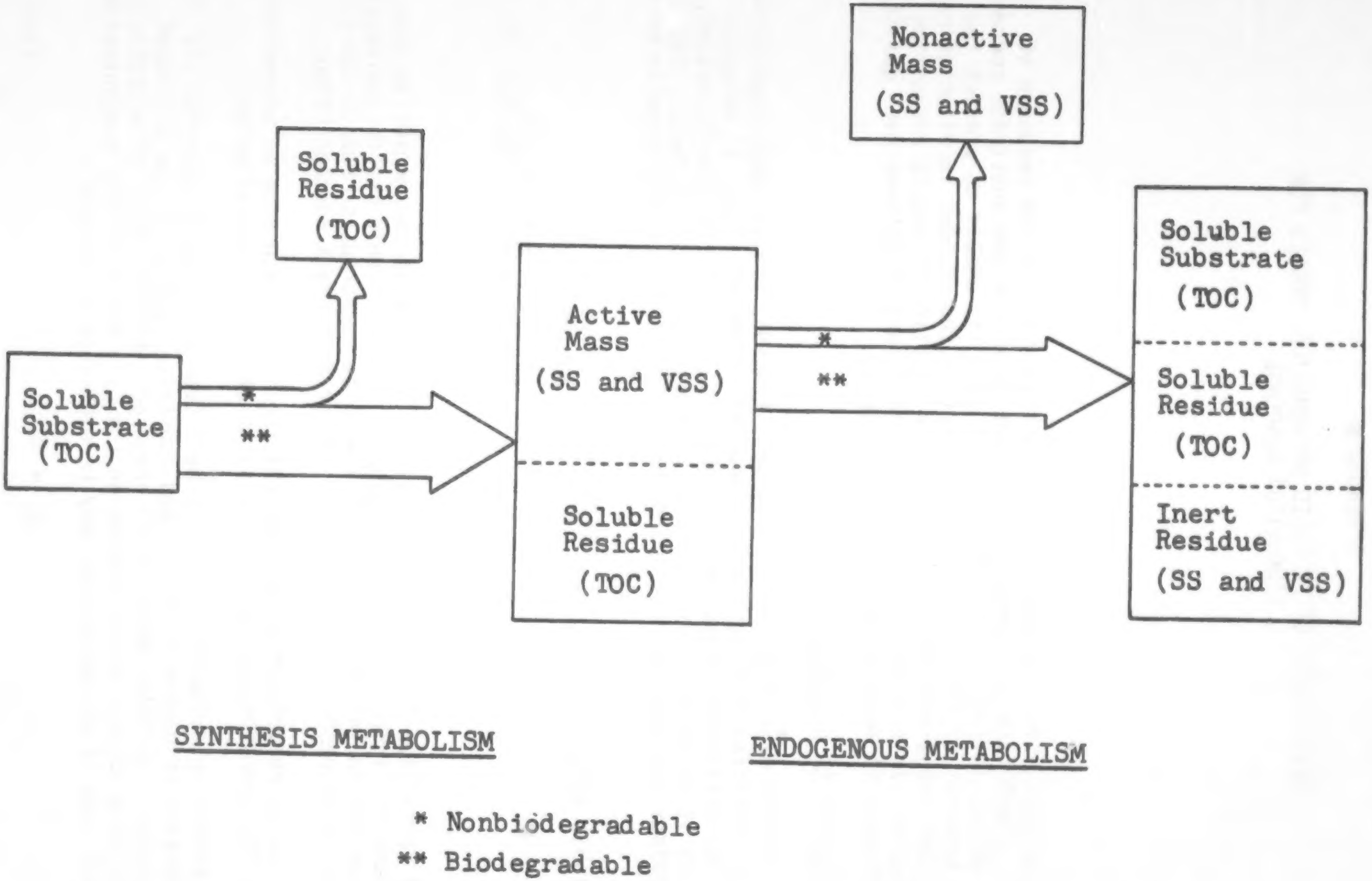

Soluble Substrate (TOC)
Soluble Residue (TOC)
*
**
Active Mass (SS and VSS)
Soluble Residue (TOC)
Nonactive Mass (SS and VSS)
*
**
Soluble Substrate (TOC)
Soluble Residue (TOC)
Inert Residue (SS and VSS)
SYNTHESIS METABOLISM
ENDOGENOUS METABOLISM
* Nonbiodegradable
** Biodegradable

Figure B-1. Microbial metabolism in soluble substrate.

where μ is the specific growth rate and X is the concentration of bacterial cells. Monod found that the value of μ is not constant, but depends on the concentration of growth limiting substrate, S, according to the equation:

$$\mu = \mu_m S/K_s + S \qquad \text{(B-3)}$$

The maximum growth rate, μ_m, and the saturation constant, K_s, are kinetic parameters, and are assumed to be constant for a specific system. When the substrate concentration is low with respect to the value of K_s, equation (B-3) may be simplified into a first order equation in the manner of Garrett and Sawyer (B-5)

$$\mu = \mu_m/K_s\ S = KS \qquad \text{(B-4)}$$

Monod also suggested that the relationship between the growth of bacteria and utilization of substrate be represented by:

$$-dS/dt = 1/Y\ dX/dt \qquad \text{(B-5)}$$

where Y is referred to as the yield factor which he assumed to be constant. This model has been widely used to predict steady state growth rate and to design the CMAS process with some success (B-6). However, Storer and Gaudy (B-1) and Sherrard (B-7) found the yield factor varies with growth rate rather than remaining constant.

Koga and Humphrey (B-2) discussed the dynamic response of a chemostat as predicted by the Monod empirical model. They concluded that the Monod model is inadequate to predict the dynamic behavior observed in chemostat experiments. Kono and Asai (B-8) introduced physiological activity in growth kinetics to account for lag phase and declining phase. According to the studies on transient loadings Young et al. (B-3) also noted that the Monod model is not satisfactory for predicting unsteady state microbial growth.

Tebbutt and Christoulas (B-9) showed that a first order reaction with retardation as proposed by Fair et al. (B-10) satisfactorily described treatment kinetic with sewage.

$$-ds/dt = KX(S/S_0)^n S \qquad \text{(B-6)}$$

For $n = 0$, equation (B-6) describes a linear kinetic model of substrate removal, it is the form as a first order reaction proposed by Tischler and Eckenfelder (B-11).

By integrating for the range $0 \leq n \leq 2$, Equation (B-6) may be expressed approximately as (B-12):

$$S_0 - S/S_0 = A(KX\theta)^B/1 + A(KX\theta)^B \qquad \text{(B-7)}$$

where:

$A = 0.585 + 0.415 \exp(-1.4695n)$

$B = 1/(1 - 0.2267n)$
θ = hydraulic residence time in the system

Grau et al. (B-13, B-14), on the basis of numerous experiments and after thorough theoretical analysis, proposed the following differential equation for multi-component substrate removal kinetics:

$$-dS/dt = K_n X(S/S_o)^n \qquad \text{(B-8)}$$

where n is the formal order of reaction. For n = 1, Equation (B-8) may be reduced to the Eckenfelder kinetic model (B-15) as:

$$-dS/dt - KX\ S/S_o \qquad \text{(B-9)}$$

Equation (B-9) logically states that the removal rate, dS/dt, decreases as the fraction of substrate remaining, S/S_o, to be moved decreases. The rationale for this rests in the fact that as the more readily removable compounds are exhausted, those yet to be removed result in a decreasing removal rate.

It is assumed that within the mixed liquor of activated sludge there exist active (or viable) cells of concentration X_a which increase in cellular mass at a rate directly proportional to their cellular mass at any time, then:

$$(dX_a/dt) \text{ synthesis} = \mu_{xa} X_a \qquad \text{(B-10)}$$

By introducing the yield factor, Y, defined as units active mass synthesized per unit soluble substrate utilized, it gives:

$$(dX_a/dt) \text{ synthesis} = -Y\ ds/dt \qquad \text{(B-11)}$$

In accordance with the concept of Sinclair and Topiwala (B-16) active mass is lost by endogenous metabolism (endogenous respiration and cellular death) to provide maintenance energy for viable cells. The rate of endogenous metabolism is assumed to be first order with respect to active cells with a constant specific rate, b:

$$(dX_a/dt)_{\text{endogenous metabolism}} = -bX_a \qquad \text{(B-12)}$$

Combining Equations (B-10) and (B-12) an expression for the net growth rate of active cells is obtained:

$$(dX_a/dt)_{\text{net growth}} = \mu_{xa} X_a - bX_a \qquad \text{(B-13)}$$

During the endogenous metabolism some of the active cells are assumed to die and release their contents back into the mixed liquor to serve again as soluble substrate for the surviving microorganisms. However, some constituents of the cell material are nonbiodegradable and remain as part of the biomass (nonactive cells). Thus, the rate of production of nonactive, but previously active, cells is proportional to the rate of breakdown of active cells due to cell lysis and endogenous respiration:

$$dX_n/dt = \alpha\, bX_a \qquad \text{(B-14)}$$

According to Kountz and Forney (B-17), approximately 75-80% of the microbial cells is biodegradable and remaining 20-25% is nonbiodegradable residue, i.e.,

$$\alpha = 0.20 - 0.25 \qquad \text{(B-15)}$$

The total volatile suspended solids in the mixed liquor is defined as:

$$X_v = X_a + X_n + X_{io} \qquad \text{(B-16)}$$

The inert organic matter, X_{io}, in the system is so small with respect to total biomass that it may be neglected and Equation (B-16) may be reduced to:

$$X_v = X_a + X_n \qquad \text{(B-17)}$$

The net rate of biomass production in the system would then be expressed as:

$$dX_v/dt = (\mu_{xa} - b + \alpha b)\, X_a \qquad \text{(B-18)}$$

In aerobic biological systems the dissolved oxygen will be consumed by microorganisms for synthesis and endogenous metabolism. The oxygen required for synthesis is proportional to the substrate utilized while the oxygen consumed during endogenous metabolism is proportional to the endogenous rate. The oxygen uptake rate is:

$$R = a'/Y\, \mu_{xa} X_a + b'\, bX_a \qquad \text{(B-19)}$$

Then the specific oxygen uptake rate may be expressed as:

$$r = a'/Y\, \mu_{xa} + b'b \qquad \text{(B-20)}$$

With material balance, mathematical relationships for each completely mixed biological treatment system may be developed for soluble substrate, active mass, and total mass. The general mass balance equation is:

$$\text{Accumulation} = \text{Input} - \text{Output} \pm \text{Conversion} \qquad \text{(B-21)}$$

It is noted that the soluble substrate concentration released by cells decomposition during endogenous metabolism is not taken into account for the overall substrate balance. Although efforts have been made about such various substrate sources (B-18, B-19) it is doubtful whether the present state of knowledge and the difficulties inherent in parameter prediction justify their use for design and operation practice.

STEADY STATE OF ACTIVATED SLUDGE UNIT

If the system shown in Figure B-2 is operated at steady state condition and the sludge is wasted daily to remain specific volatile suspended solids for various influent substrate concentrations, the mass balance equations

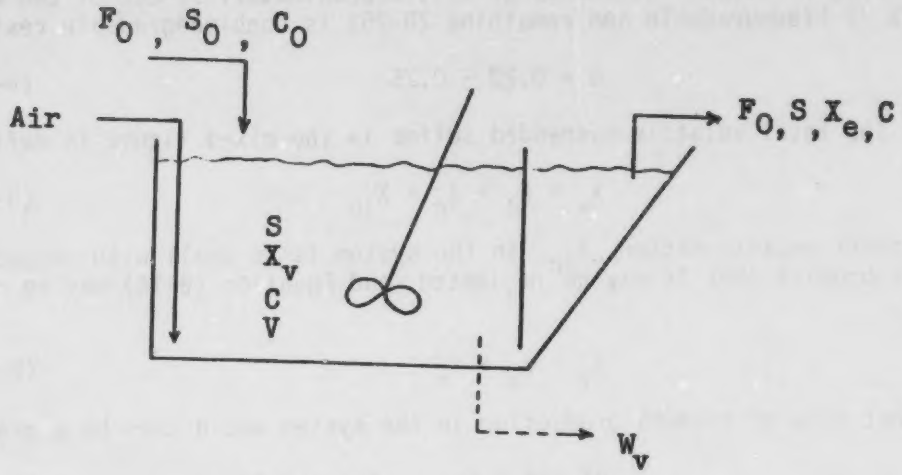

F_O , S_O , C_O
Air
F_O, S ,X_e, C
S
X_v
C
V
W_v

Figure B-2. Schematic of activated sludge unit.

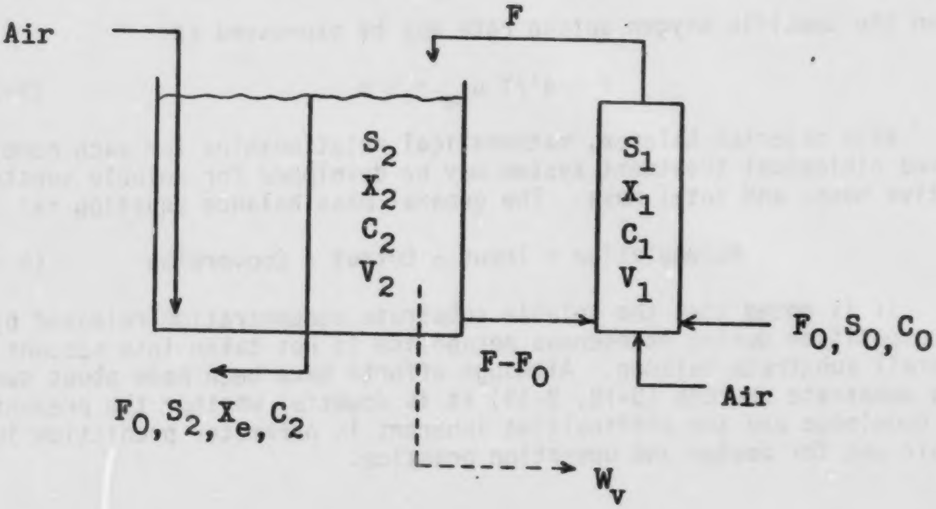

Air
F
S_2
X_2
C_2
V_2
S_1
X_1
C_1
V_1
F_O,S_O,C_O
F-F_O
Air
F_O,S_2,X_e,C_2
W_v

Figure B-3. Schematic of BioMonitor.

for soluble substrate, active mass, and total mass are:

Soluble Substrate Balance

$$0 = F_o(S_o - S) - 1/Y\ \mu_{xa}X_aV \qquad \text{(B-22)}$$

Active Mass Balance

$$0 = 0 - F_oX_{ae} - W_a + \mu_{xa}X_aV - bX_aV \qquad \text{(B-23)}$$

Total Mass Balance

$$0 = 0 - F_oX_{ve} - W_v + (\mu_{xa} - b + \alpha b)\ X_aV \qquad \text{(B-24)}$$

If all biomass are homogeneously mixed within the aeration basin and the clarifier and the accumulation of biomass in the clarifier is negligible, i.e.:

$$X_a/X_v = X_{ae}/X_{ve} = W_a/W_v \qquad \text{(B-25)}$$

Thus, the definition of mean cell residence time may be written as:

$$\theta_c = X_vV/F_oX_{ve} + W_v = X_aV/F_oX_{ae} + W_a \qquad \text{(B-26)}$$

Equation (B-23) can be rearranged and Equation (B-26) can be substituted into the result to give:

$$\mu_{xa} = 1/\theta_c + b \qquad \text{(B-27)}$$

Substituting Equation (B-27) into Equation (B-22), it gives:

$$X_a = \theta_cY(S_o - S)/\theta(1 + b\theta_c) \qquad \text{(B-28)}$$

where θ is hydraulic residence time, V/F_o. Substituting Equations (B-26), (B-27) and (B-28) into Equation (B-24) and solving for X_v, it yields:

$$X_v = Y(S_o - S)\ \theta_c/\theta\ (1 + \alpha b\theta_c)(1 + b\theta_c) \qquad \text{(B-29)}$$

The activity of the mixed liquor in activated sludge system is defined as the active cell fraction, i.e., the active mass divided by the total biomass. Hence, the activity, x, may be shown:

$$x = X_a/X_v = 1/1 + \alpha b\theta_c \qquad \text{(B-30)}$$

STEADY STATE EVALUATION OF BIOMONITOR

Based on the schematic diagram of the BioMonitor shown in Figure B-3 at steady state the material balance on soluble substrate, active mass, total mass, and oxygen concentration will yield:

Contact Chamber

Soluble Substrate Balance

$$0 = F_oS_o + (F - F_o)S_2 - FS_1 - 1/Y_1 \mu_{xa1} X_{a1}V_1 \qquad \text{(B-31)}$$

Active Mass Balance

$$0 = (F - F_o)X_{a2} - FX_{a1} + \mu_{xa1}X_{a1}V_1 - b_1X_{a1}V_1 \qquad \text{(B-32)}$$

Total Mass Balance

$$0 = (F - F_o)X_{v2} - FX_{v1} + (\mu_{xa1} - b_1 + \alpha b_1)X_{a1}V_1 \qquad \text{(B-33)}$$

Oxygen Concentration Balance

$$0 = F_oC_o + (F-F_o)C_2 - FC_1-R_1V_1 + K_La_1(C_1*-C_1)V_1 \qquad \text{(B-34)}$$

Aeration Basin

Soluble Substrate Balance

$$0 = FS_1-(F-F_o)S_2 - F_oS_2 - 1/Y_2 \mu_{xa2}X_{a2}V_2 \qquad \text{(B-35)}$$

Active Mass Balance

$$0 = FX_{a1}-(F-F_o)X_{a2}-F_oX_{ae}-W_a + \mu_{xa2}X_{a2}V_2-b_2X_{a2}V_2 \qquad \text{(B-36)}$$

Total Mass Balance

$$0 = FX_v1-(F-F_o)X_{v2}-F_oX_{ve}-W_v + (\mu_{xa2}-b_2+\alpha b_2)X_{a2}V_2 \qquad \text{(B-37)}$$

Oxygen Concentration Balance

$$0 = FC_1-(F-F_o)C_2-F_oC_2-R_2V_2 + K_La_2(C_2*-C_2)V_2 \qquad \text{(B-38)}$$

At steady state the microorganisms both in contact chamber and the aeration basin provide the same physiological state, i.e., same activity, thus:

$$X_{a1}/X_{v1} + X_{a2}/X_{v2} = X_{ae}/X_{ve} = W_a/W_v \qquad \text{(B-39)}$$

also $b_1 = b_2 = b, \ Y_1 = Y_2 = Y$

From Equations (B-32) and (B-33) and Equations (B-36) and (B-37), it is evident that:

$$\mu_{xa1} = \mu_{xa2} = \mu_{xa} \qquad \text{(B-40)}$$

Equations (B-31-33) and Equations (B-35-37) may be rewritten as follows:

Contact Chamber

$$0 = F_oS_o + (F-F_o)S_2 - FS_1 - 1/Y\ \mu_{xa}X_{a1}V_1 \qquad \text{(B-41)}$$

$$0 = (F-F_o)X_{a2} - FX_{a1} + \mu_{xa}X_{a1}V_1 - b\ X_{a1}V_1 \qquad \text{(B-42)}$$

$$0 = (F-F_o)X_{v2} - FX_{v1} = (\mu_{xa} - b + \alpha b)X_{a1}V_1 \qquad \text{(B-43)}$$

Aeration Basin

$$0 = FS_1 - (F-F_o)S_2 - F_oS_2 - 1/Y\ \mu_{xa}X_{a2}V_2 \qquad \text{(B-44)}$$

$$0 = FX_{a1} - (F-F_o)X_{a2} - F_oX_{ae} - W_a + \mu_{xa}X_{a2}V_2 - bX_{a2}V_2 \qquad \text{(B-45)}$$

$$0 - FX_{v1} - (F-F_o)X_{v2} - F_oX_{ve} - W_b + (\mu_{xa} - b + \alpha b)X_{a2}V_2 \qquad \text{(B-46)}$$

Now the mean cell residence time may be defined as:

$$\theta_{c1} = X_{v1}V_1/FX_{v1} - (F-F_o)X_{v2} = X_{a1}V_1/FX_{a1} - (F-F_o)X_{a2} \qquad \text{(B-47)}$$

$$\theta_{c2} = X_{v2}V_2/(F-F_o)X_{v2} + F_oX_{ve} + W_v - FX_{v1} =$$

$$X_{a2}V_2/(F-F_o)X_{a2} + F_oX_{ae} + W_a - FX_{a1} \qquad \text{(B-48)}$$

Substituting and rearranging Equations (B-41)-(B-46), it yields:

Contact Chamber

$$\mu_{xa} = 1/\theta_{c1} + b \qquad \text{(B-49)}$$

$$x_{a1} = Y/V_1[F_o(S_o-S_2) + F(S_2-S_1)]/(1/\theta_{c1} + b) \qquad \text{(B-50)}$$

$$X_{v1} = Y[F_o(S_o-S_2)$$

$$+ F(S_2-S_1)]\ \theta_{c1}/V_1\ (1 + \alpha b\theta_{c1})/(1 + b\theta_{c1}) \qquad \text{(B-51)}$$

Aeration Basin

$$\mu_{xa} = 1/\theta_{c2} + b \qquad \text{(B-52)}$$

$$X_{a2} = Y/V_2\ F(S_1-S_2)/((1/\theta_{c2}) + b) \qquad \text{(B-53)}$$

$$X_{v2} = Y\ F(S_1-S_2)\ \theta_{c2}/V_2\ (1 + \alpha b\theta_{c2})/(1 + b\theta_{c2}) \qquad \text{(B-54)}$$

From Equations (B-49) and (B-52) it gives:

$$\theta_{c1} = \theta_{c2} = \theta_c \qquad \text{(B-55)}$$

DYNAMIC MODELS OF THE BIOMONITOR

At unsteady state conditions equations derived for steady state may be modified and give:

Contact Chamber

Soluble Substrate Response

$$V_1\ dS_1/dt = F_oS_o + (F-F_o)S_2 - FS_1 - 1/Y\ \mu_{xa1}X_{a1}V_1 \tag{B-56}$$

Active Mass Response

$$V_1\ dX_{a1}/dt = (F-F_o)X_{a2} - FX_{a1} + \mu_{xa1}X_{a1}V_1 - b\ X_{a1}V_1 \tag{B-57}$$

Total Mass Response

$$V_1dX_{v1}/dt = (F-F_o)X_{v2} - FX_{v1} + (\mu_{xa1}-b+\alpha b)X_{a1}V_1 \tag{B-58}$$

Oxygen Concentration Response

$$\begin{aligned} V1\ dC_1/dt = {} & F_oC_o + (F-F_o)C_2 - FC_1 - R_1V_1 \\ & + K_La_1(C^*-C_1)V_1 \end{aligned} \tag{B-59}$$

Aeration Basin

Soluble Substrate Response

$$V_2\ dS_2/dt = FS_1 - FS_2 - 1/Y\ \mu_{xa2}X_{a2}V_2 \tag{B-60}$$

Active Mass Response

$$\begin{aligned} V_2\ dX_{a2}/dt = {} & FX_{a1} - (F-F_o)X_{a2} - F_oX_{ae} - W_a \\ & + \mu_{xa2}X_{a2}V_2 - bX_{a2}V_2 \end{aligned} \tag{B-61}$$

Total Mass Response

$$\begin{aligned} V_2dX_{v2}/dt = {} & FX_{v1} - (F-F_o)X_{v2} - F_oX_{ve} - W_v \\ & + (\mu_{xa2} - b + \alpha b)X_{a2}V_2 \end{aligned} \tag{B-62}$$

Oxygen Concentration Response

$$V_2dC_2/dt = FC_1 - FC_2 - R_2V_2 + K_La_2(C^* - C_2)V_2 \tag{B-63}$$

By applying the process parameter values evaluated from steady state condition dynamic models may be conducted to examine the responses to transient loadings by computer simulation. The results should be compatible to experimental data if the dynamic models work.

LIST OF ABBREVIATIONS AND SYMBOLS

ABBREVIATIONS

a' -- oxygen consumed per unit substrate utilized, dimensionless
b -- endogenous metabolism rate, T^{-1}
b' -- oxygen required per unit active biomass lost by endogenous metabolism, dimensionless
C -- dissolved oxygen concentration, ML^{-3}
C^* -- saturated dissolved oxygen concentration, ML^{-3}
C_s -- steady state dissolved oxygen concentration, ML^{-3}
F -- flow rate, L^3T^{-1}
K -- reaction rate constant, T^{-1} or $M^{-1}L^3T^{-1}$
K_La -- overall oxygen transfer coefficient, T^{-1}
k_n -- nth order reaction rate constant, T^{-1}
K_s -- saturation constant, ML^{-3}
R -- oxygen uptake rate by microorganisms, $ML^{-3}T^{-1}$
r -- specific oxygen uptake rate by microorganisms, T^{-1}
S -- soluble substrate concentration, ML^{-3}
V -- reactor volume, L^3
W_a -- active biomass wasted per day, MT^{-1}
W_v -- volatile suspended solids wasted per day, MT^{-1}
x -- active biomass fraction in mixed liquor, dimensionless
X_a -- active biomass concentration, ML^{-3}
X_{ae} -- active biomass concentration in effluent, ML^{-3}
X_{io} -- inert organics concentration, ML^{-3}
X_n -- nonactive biomass concentration, ML^{-3}
X_v -- volatile suspended solids concentration, ML^{-3}
Y -- yield factor, dimensionless
α -- nonbiodegradable fraction of microbial cell materials, dimensionless
μ -- specific growth rate, T^{-1}
μ_m -- maximum specific growth rate, T^{-1}
μ_{xa} -- microbial synthesis rate, T^{-1}
θ -- hydraulic residence time, T
θ_c -- mean cell residence time, T

SUBSCRIPTS

0 -- influent
1 -- contact chamber
2 -- aeration basin

REFERENCES

B-1 Storer, F.F., and Gaudy, A.F., Jr. "Computational Analysis of Transient Response to Quantitative Shock Loadings of Heterogeneous Populations in Continuous Culture," Enviro. Sci. Tech., 3, 143-149 (1969).

B-2 Koga, S. and Humphrey, A.E. "Study of the Dynamic Behavior of the Chemostat System," Biotech. Bioeng., 9, 375-386 (1967).

B-3 Young, T.B.; Bruley, D.F.; and Bungay, H.R. III. "A Dynamic Mathematical Model of the Chemostat," Biotech. Bioeng., 12, 747-769 (1970).

B-4 Monod, J. "Recherches sur la Croissances des Cultures Bacteriennes," Hermann et Cie, Paris (1942).

B-5 Garrett, M.T., Jr. and Sawyer, C.N. "Kinetics of Removal of Soluble BOD by Activated Sludge," Proc. 7th Ind. Waste Conf., Purdue Univ., West Lafayette, Indiana (1952).

B-6 Lawrence, A.W., and McCarty, P.L. "Unified Basis for Biological Treatment Design and Operation," J. San. Eng. Div., ASCE, 96, 757-778 (1970).

B-7 Sherrard, J.H. Ph.D. Thesis, Univ. of California, Davis (1971).

B-8 Kono, T. and Asai, T. "Kinetics of Continuous Cultivation," Biotech. Bioeng., 11, 19-36 (1969).

B-9 Tebbutt, T. H. Y., and Christoulas, D.G. "Performance Studies on a Pilot-Scale Activated Sludge Plant," Water Poll. Cont., 74, 701-710 (1975).

B-10 Fair, G.M.; Geyer, J.C.; and Okun, D. "Water and Wastewater Engineering," Vol 2, John Wiley & Sons, Inc., New York (1968).

B-11 Tischler, L.F., and Eckenfelder, W.W., Jr. "Linear Substrate Removal in the Activated Sludge Process," Proc. 4th Int'l. Water Poll. Res. Conf., Prague (1969).

B-12 Christoulas, D.G., and Tebbutt, T.H.Y. "Mathematical Model of a Complete-Mix Activated Sludge Plant," Water Res., 10, 797-804, (1976).

B-13 Grau, P., and Dohanyos, M. "Substrate Removal Kinetics of Activated Sludge," Vod. Hospod. B20, 298-305 (In Czech) (1970).

B-14 Grau, P.; Dohanyos, M.; and Chudoba, J. "Kinetics of Multi-Component Substrate Removal by Activated Sludge," Water Res., 9, 637-642 (1975).

B-15 Adams, C.E., Jr.; Eckenfelder, W.W.; and Hovious, J.C. "A Kinetic Model for Design of Completely Mixed Activated Sludge Treating Variable-Strength Industrial Wastewater," Water Res., 9, 37-42 (1975).

B-16 Sinclair, C.G., and Topiwala, H.H. "Model for Continuous Culture which Considers the Viability Concept," Biotech. Bioeng., 12, 1069-1079 (1970).

B-17 Kountz, R.R. and Forney, C., Jr. "Metabolic Energy Balances in a Total Oxidation Activated Sludge System," Sew, Ind. Wastes, 31, 819-826 (1959).

B-18 Martin, E.J., and Washington, D.R. "Kinetics of the Steady-State Bacterial Culture-I. Mathematical Model," Proc. 19th Ind. Waste Conf., Purdue Univ., West Lafayette, Indiana (1964).

B-19 Westberg, N. "A Study of the Activated Sludge Process as a Bacterial Growth Process," Water Res., 1, 795-804 (1967).

APPENDIX C

PILOT PLANT INVESTIGATIONS

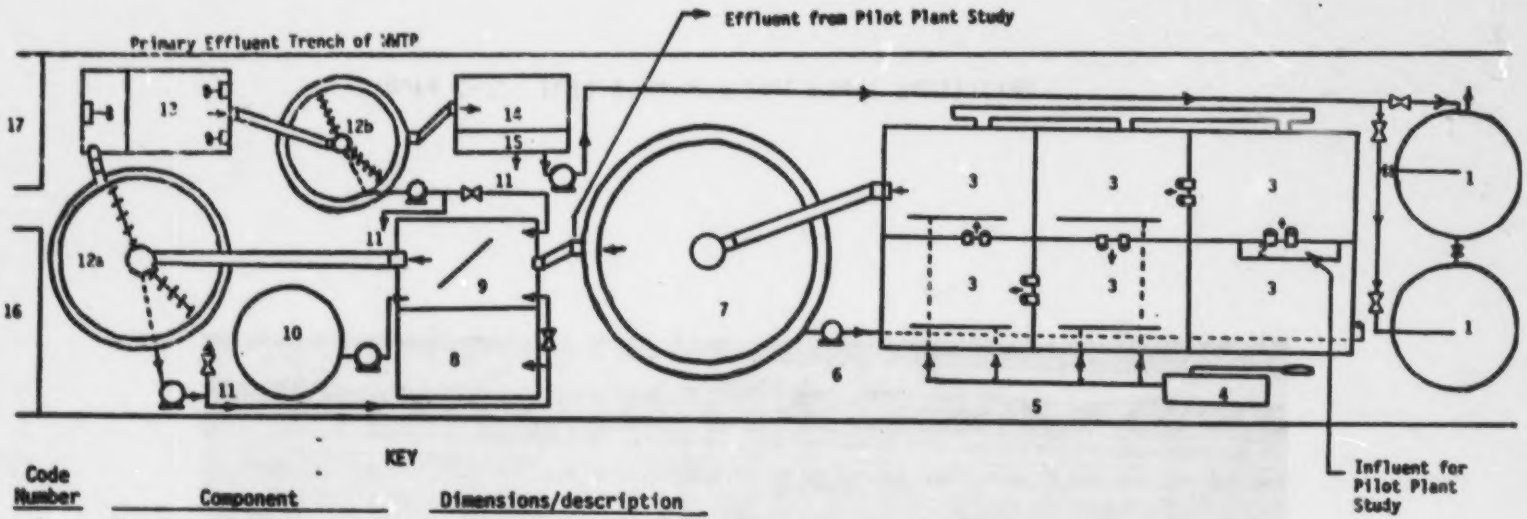
DESCRIPTION OF PILOT PLANT

Figure C-1 is a detailed schematic of the pilot plant system with the various components defined. Actual pictures of the system are seen in Figures C- 2 and C- 3 . The trailer holding the components is 40 feet long by 8 feet wide. The pilot plant consists of six plug flow aeration basins with an approximate volume of 300 gallons (252 cubic feet) each. Each compartment measures 3' x 2' x 7' deep. The total outside dimensions are 9' x 4' x 7.8' deep. The effective standing water depth is 7 feet. The effluent from basin six enters a secondary clarifier set up for return sludge to basin one. The biological clarifier is 7 feet in diameter at wier level with a surface area of 38.5 square feet. The maximum flow through the system is 13.4 gallons per minute.

Baseline feed to the system is the primary effluent from Metro's (Nashville's) Central Sewage Treatment System. The average BOD for the primary effluent during the test period was approximately 110 mg/l. Metro Central Wastewater Treatment Plant has a capacity of 68 MGD. Feed is pumped in at 1.7 gallons per minute. The return sludge is pumped in at 3.5 gallons per minute in an effort to maintain a solids level of 3500 mg/l MLSS and 2500 mg/l MLVSS. This combined flow of 5.2 gallons per minute effects a one hour retention per basin for a total system retention time of six hours. Minimum retention time for the system is 2.34 hours for 6 basins, of 0.39 hours per basin.

A dye study was performed to determine the flow pattern of the pilot plant, i.e., breakthrough times of the individual basins. Three mls of Rhodamine W.T. dye (concentration 21,000 ppm) was added to aeration basin I. Percent transmission was read on an Aminco Fluoro-Micro Photometer set at a meter multiplier of 0.3 and a sensitivity of 30%. Maximum percent transmission was set at 100% with tap water and dye. The zero percent transmission blank was tap water. Influent flow during the study was 2.2 gpm and return sludge was 3.2 gpm for a total of 5.4 gpm flow through the system. The average effective volume of each of the 6 basins is 314 gallons. Therefore, the theoretical retention time at this flow was 58 minutes or 0.967 hours.

A problem seemed to occur with the fluorometer measurements approximately 2 hours into the proposed five hour study. There arose the possibility that a local textile manufacturer was discharging (as it is known to do) some of its red dye which was fluorescing and confusing the measurements. The


Effluent from Pilot Plant Study
Primary Effluent Trench of WWTP
17
16
13
12b
12a
14
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3
3
1
1
Influent for Pilot Plant Study

KEY

Code Number	Component	Dimensions/description
1	Pressure filter	3' diameter, 5.7' high
2	Splitter box	
3	Aeration basin	3' x 2", 7'swd* overall dimensions 9' x 4' x 7.8'
4	Air compressor	5 hp, 3495 rpm
5	Air system & flow meters	
6	Secondary sludge return pump	1.5 hp, 1725 rpm variable speed
7	Biological clarifier	ID, 7.3'; OD, 8' 2' swd
8	Chemical sludge thickener	
9	Flocculation tank	3' x 4' x 4.5'
10	Line tank	2.2' diameter; 5.9' deep
11	"to waste"	
12	Chemical clarifier	a) 5' diameter; 2.5 swd b) 3' diameter' 4.5 swd
13	Mixing tank - baffled	tank: 2' x 6' x 4' deep mixers: ⅛ hp, 1725 rpm
14	Flow splitter	1⅛ hp, 1750 rpm
15	Tank	
16	Pump regulators	
17	Electrical control box	

*swd = standing water depth

Figure C-1. Detailed schematic of pilot plant.

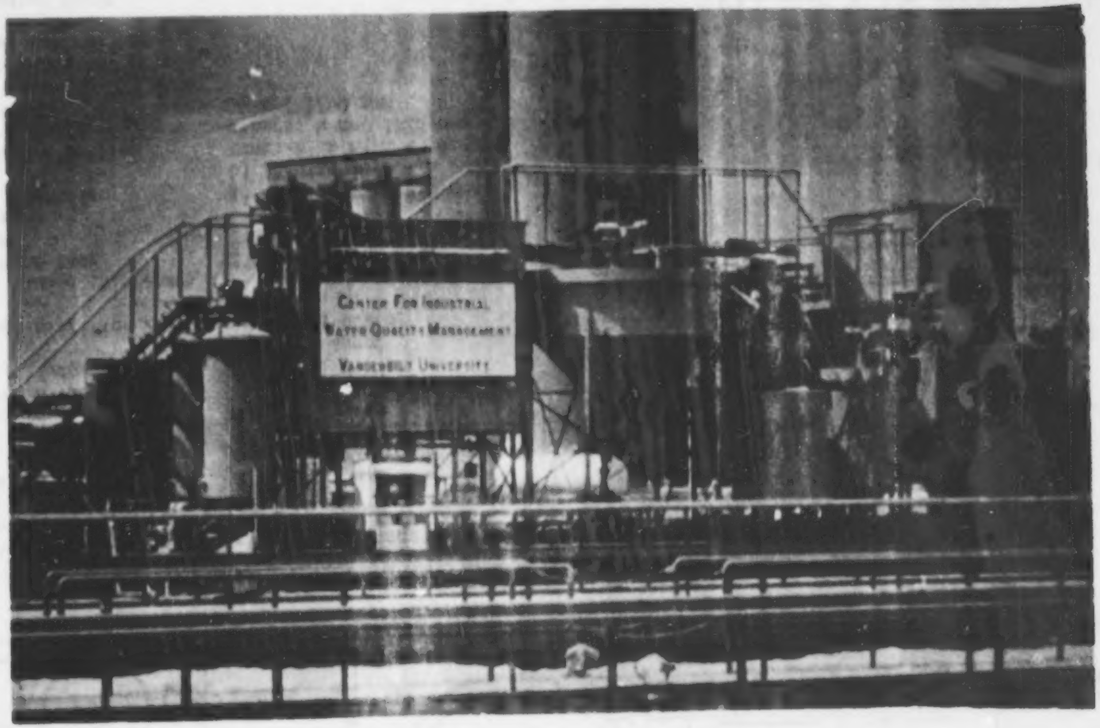

CENTER FOR INDUSTRIAL
WATER QUALITY MANAGEMENT
VANDERBILT UNIVERSITY

Figure C-2. Full View of Pilot Plant Facilities

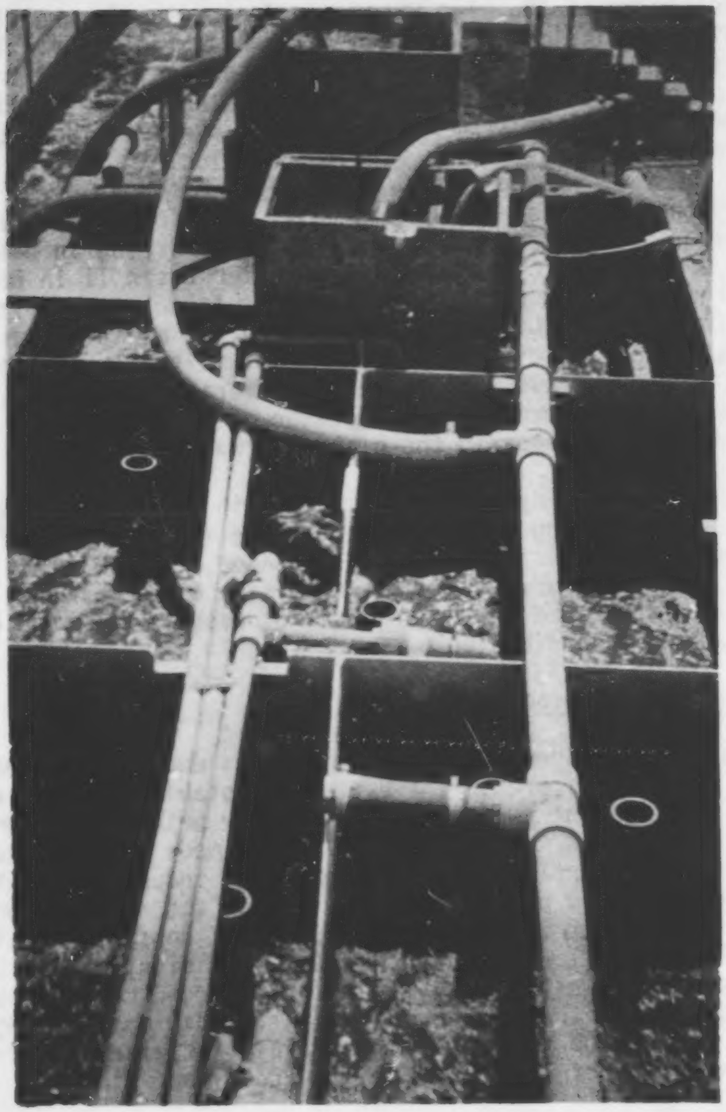


Figure C-3. Close-up of Pilot Plant Aeration Basins study was continued through approximately 3 1/2 hours with plans to restudy the problem at a later date.

A second dye study was performed 2 weeks later. This delay permitted the system to flush itself of residual dye. Operating parameters at this time were: same fluorometer as previously employed with the same meter multiplier of 0.3 but a sensitivity of 37. Tap water and dye was again the blank used to calibrate 100% transmission. The "zero" blank was tap water. There was one major difference. Tap water at a rate of 5.4 gpm was pumped into the system in place of the raw sewage feed and return sludge. This eliminated not only the spurious readings from the industrial dye but also reduced the possible errors due to dye adsorption onto the biofloc.

Theoretically the basin is a plug flow unit; therefore, the theoretical breakthrough of dye in each compartment is a spike occurring in basin II one hour after the dye is added to basin I; 1 hour after basin II in basin III, etc. The breakthrough point in the clarifier was taken at the first significant increase in the reading. The values listed for aeration basin I indicate the time at which the dye reached the level initially monitored in the clarifier. Background levels in the basins averaged about 12%. Mixed liquor was in the basins before the introduction of the tap water. The background level of fluorescence in the clarifier was around 3%.

The results of these two dye studies are seen in Table C-1. The results indicate some short-circuiting in the system. Time from peak to peak should be one hour. Our data reveal travel times (distance between peaks) of 1.42, 0.50, 0.83, 0.83 and 0.67 hours for an average value of 0.85 hours. This information will be integrated in the analysis of results obtained during the shocking procedures described below.

Industrial Wastes Shock Program

The following general experimental procedure was employed for each of the three industrial wastes monitored. The system was stabilized with respect to solids level and equipment performance. The WWTP primary effluent was pumped to the splitter box. Adjustment in flow was made both at the pump and by variation in the overflow gate position. The industrial waste used to shock the system was also pumped into the flow at the splitter box. Adjustment in flow was made at the pump. An additional contact container below the splitter box outfall was added to effect sufficient mixing between the sewage and industrial waste. It was from this second contact container that the sample was pumped to the BioMonitor. The additional mixing container and longer connecting tubing caused a delay (increase cf laboratory studies) in response time of the BioMonitor to about four minutes.

The BioMonitor, pumps, meter and recorder were set up in a weather station box alongside the trailer. Figures C-4 and C-5 show the setup employed. A second weather station box was set up on the trailer bed. This housed equipment, additional supplementary tests, materials for oxygen uptakes, maintenance paraphernalia, clean-up accessories, etc.

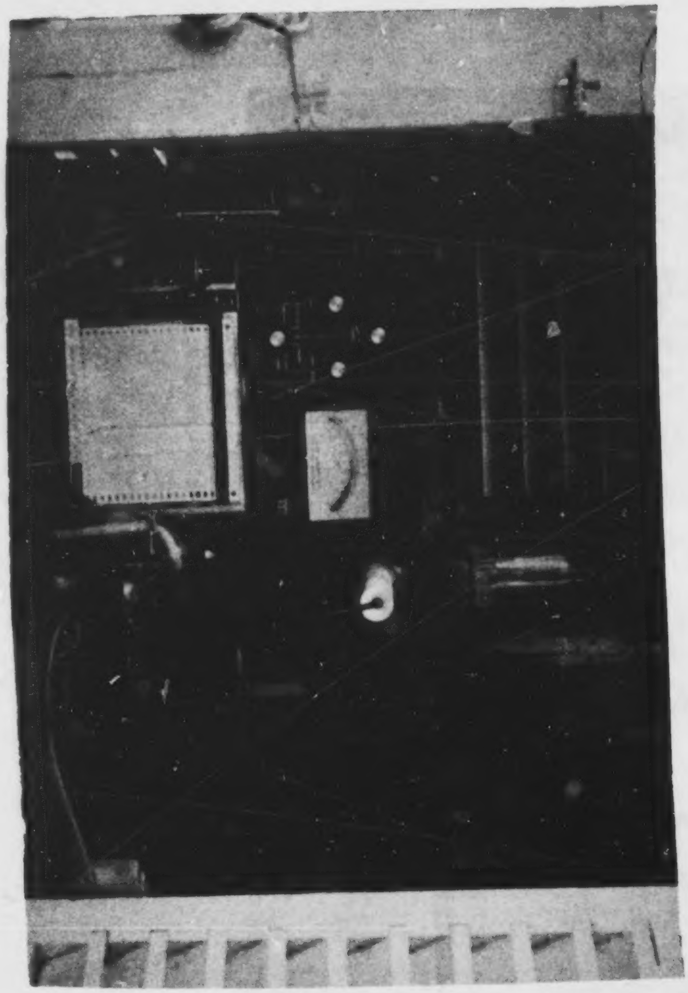


Figure C-4. Close-up of BioMonitor at pilot plant

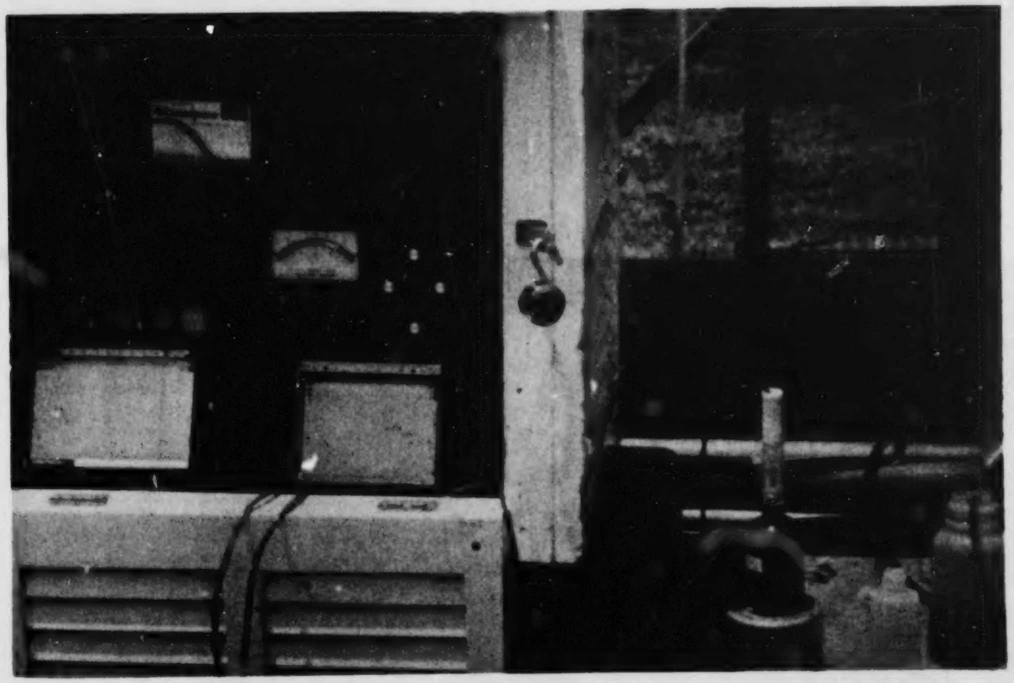


Figure C-5. Close-up of auxiliary equipment at pilot plant

TABLE C-1. RESULTS OF PILOT PLANT DYE STUDIES

Location, Basin#	Breakthrough Time, hours* 7/19 Study	8/3 Study	Theoretical
1**	not reached @3.4 hr	3.67	
2	1.27	1.42	1.00
3	1.74	1.92	2.00
4	1.74	2.75	3.00
5	1.96	3.58	4.00
6	1.96	4.25	5.00
clarifier	2.8	-	6.00

*After addition of dye to aeration basin I.

**Time at which aeration basin I is flushed to the fluorescence level initially monitored in the clarifier.

The testing and sampling program set up at the pilot plant was as follows: the shock load applied for 15 minutes. The baseline feed flow was reduced by the flow of waste to maintain the same retention time. A single shock load was studied per day. Fresh industrial wastewater was brought in daily. They were transported in plastic-lined 55 gallon drums. The wastes studied in this part of the project were: (a) food (potato) processing; (b) meat processing; and (c) electroplating. The schedule of the pilot plant sampling program is given in Table C-2.

Potato Processing Waste--

The potato processing waste had an average BOD of 256 mg/l and a TOC of 230 mg/l. The waste was at a very high pH (≈ 11) because of a caustic peel/cleaning step in the process.

During the three days of testing the potato processing waste, the return sludge flow was maintained at 3.5 gpm. The sewage feed flow to the pilot plant was controlled at 1.8 gpm for the one day and 1.65 gpm for two days. The shock flows of potato processing wastes were: 1.8 gpm (or 100% on day one) and 1.2 and 0.6 gpm on the two 1.65 gpm days (73% and 36, respectively). Shock loading with potato waste was applied to a steady-state system (with reference to the DO level in the BioMonitor) and lasted 15 minutes. The effect of the shock was then monitored through the pilot plant system for 6 hours. The BioMonitor unit at the time of the tests had a feed flow rate of 20 ml/min and an average return rate of ≈ 70 ml/min.

Upon addition of the potato waste at the 36% and 100% contribution of the total feed flow the change in DO was positive (i.e., DO increased).The 73% contribution caused a decline in DO level. Assuming minimum variability in the waste as supported by individual TOC analyses on each day's

TABLE C-2. PILOT PLANT SAMPLING PROGRAM

	Biomonitor				A.B. I				A.B. IV				A.B. VI			
Time*	DO	Solids	TOC	O_2***	DO	Solids	TOC	O_2	DO	Solids	TOC	O_2	DO	Solids	TOC	O_2
continuous	X				X											
before		X				X	X	X			X	X			X	X
0							X	X								
7 min							X	X								
15 min							X	X								
30 min							X	X								
1 hr**							X	X			X	X			X	X
2 hr							X	X			X	X			X	X
3 hr							X	X			X	X			X	X
4 hr							X	X			X	X			X	X
5 hr							X	X			X	X			X	X

*With reference to shock period - "0" is beginning of shock

**TOC samples are collected at one time on the hour from all three basins. O_2 uptake samples are on the hour, quarter hour and half hour for aeration basins 1, 4, and 6, respectively.

***Oxygen uptake

waste and the simple nature of the industrial process involved, the following explanation is submitted: one problem plagued both the reproducibility and correlation of data throughout the pilot plant study. Specifically, this is the inherent variability of the feed stream (raw sewage) at the large WWTP. A study was made to test the variation in the influent flow. TOC was the monitoring parameter. The results are seen in Table C-3. A large variation is seen in Aeration Basin I. The variations are less in later basins as anticipated.

TABLE C-3. TOC ANALYSES - "STEADY STATE"*

Time into Shock	A.B. I	A.B. IV	A.B. VI
0	74.7	85.3	107.8
7 min	90.9		
15 min	86.9		
30 min	116.0		
1 hr	43.8	92.5	69.2
2 hr	80.9	66.9	69.2
3 hr	64.0	58.8	76.3
4 hr	114.9	78.8	74.0
5 hr	102.3	72.2	74.2

*No external shock applied; reflects natural variations.

Average TOC values, mg/l, including variances are: AB I 86.0 ± 28%; AB IV 75.8 ± 16%; and AB VI 78.5 ± 19%. Samples were obtained from the pilot plant for this study when no external shock was applied. Therefore, the BioMonitor is measuring not only the industrial "overlay" but also the natural week-day variations.

To test the accuracy of our results, a split sample was run with EPA's RSKERL Laboratory on the TOC analyses of filtered mixed liquor from the pilot plant aeration basins. The results are seen in Table C-4.

It was possible, however, for the BioMonitor to exhibit relatively stable periods. But again, such times were unpredictable. Preliminary work was performed on DO changes in quiet times to later analyze the significant of the change in DO in the BioMonitor during shock periods. The results are as follows: over the five hour monitoring period the variation in DO level during nonshock periods averaged ± 0.05 ppm O_2 in a 15 minute time span. The standard deviation (σ) was ± 0.03 ppm ($3\sigma = \pm\ 0.09$ ppm O_2). Again, this variability is neither predictable nor controllable. While this quality serves the project well for the on-site location studies, it is not conducive to good results when shocking in the "overlay" manner described. Similarly, this problem was avoided in the laboratory by adding the shock to an inten-

TABLE C-4. TOC ANALYSIS - SPLIT SAMPLE (MG/L)

Sample	Kerr	VU	% difference*
A.B. 1	35.5	37.8	3.1
A.B. 2	36.5	39.0	3.3
Avg. filter paper leachate	8	5	

*% difference = ((VU-Kerr)/(VU+Kerr)) x 100

tionally very reproducible and steady baseline feed. The laboratory results were reproducible and able to be meaningfully correlated as discussed earlier. Fortunately, the pilot plant is an artificial, contrived situation and as such not to be routinely encountered when the BioMonitor is in actual use.

Specifically, it appears that during the test at the 73% level some constituent in the sewage caused the DO level to decrease or conversely - something else during the other two tests caused the DO to increase. Because of the high pH of the waste the possibility of inhibition seems strong and so that the former conjucture (a spurious DO decrease) seems the more probable.

Table C-5 lists the ΔDO values found for the three levels of shock loading. Considering only the absolute magnitude of the change there is good correlation between ΔDO with time into shock period for all 3 cases individually. However, the ΔDO does not correlate magnitude of shock applied for the two positive ΔDO cases. This too could be a result of other components in the feed working against the anticipated magnitude of change.

TABLE C-5. ΔDO, PPM, IN BIOMONITOR POTATO PROCESSING WASTE-PILOT PLANT STUDY

Time into Shock, minutes	Percent Waste		
	36	73	100
0	0	0	0
2	-	-	0.04
4	0.02	-0.07	0.12
8	0.57	-0.25	0.14
12	0.80	-0.42	0.19
15	1.00	-0.50	0.24

Oxygen uptakes were performed on the aeration basin liquor of the pilot plant during these three shock runs. Samples were taken from aeration basins I, IV, and VI. The results are seen in Tables C-6, C-7 and C-8. An oxygen uptake should decrease to correlate correctly with an increase in DO, and, conversely, increase to correlate correctly with a decrease in DO. The volume of the shock compared to the volume in the pilot plant's aeration basins was small. As evidenced in the results of our oxygen uptake studies, so was its effect. Variation in the oxygen uptake essentially reflectedthe changes in raw sewage stream composition.

TABLE C-6. OXYGEN UPTAKE DATA (MG/L/HR)
POTATO PROCESSING WASTE - 36%

Time into Shock	A.B. I*	A.B. IV	A.B. VI
before	28.8	21.6	18.8
0	22.5		
7 min	25.0		
15 min	28.0		
30 min	29.2		
1 hr	42.4	21.0	21.8
2 hr	63.0	20.0	17.7
3 hr	28.0	16.0	13.0
4 hr	34.8	15.6	15.0

*A.B. = aeration basin

TABLE C-7. OXYGEN UPTAKE DATA (MG/L/HR)
POTATO PROCESSING WASTE - 73%

Time into shock	A.B. I*	A.B. IV	A.B. VI
before	21.6	19.2	18.0
0	24.3		
7 min	25.5		
15 min	33.3		
30 min	23.4		
1 hr	29.7	19.8	19.2
2 hr	51.0	24.3	21.3
3 hr	63.8	21.0	19.2
4 hr	68.4	19.8	22.5
5 hr	63.9	20.2	19.2

*A.B. = aeration basin

TABLE C-8. OXYGEN UPTAKE DATA (MG/L/HR) POTATO PROCESSING WASTE - 100%

Time into Shock	A.B. I*	A.B. IV	A.B. VI
before		23.1	24.3
0	19.8		
7 min	48.0		
15 min	41.6		
30 min	39.0		
1 hr	30.0	21.6	21.0
2 hr	30.0	21.6	21.0
3 hr	34.5	19.2	21.0
4 hr	36.9	21.0	22.6
5 hr	34.5	22.2	21.4

*A.B. = aeration basin

Table C-9 lists the results of TOC analyses during the three shock periods and for 6 hours afterwards. All TOC analyses were performed on a Beckman 915 Total Carbon Analyzer. Again, the variation in results seemed to reflect changes in the raw sewage composition rather than a meaningful correlation with the shock application and diminution.

Later in an effort to obtain more meaningful data a series of short snocks using the potato processing waste was performed. The oxygen uptake was monitored. The data is given in Table C-10. While the oxygen uptakes of the shock periods are uniformly higher than those values obtained for the "normal" feed periods preceeding them, the difference is not significant. The accuracy of an oxygen uptake test is probably on the order of ± 10%. As such, this data also appears inconclusive.

TABLE C-9. POTATO PROCESSING WASTE - PILOT PLANT STUDY TOC VALUES (MG/L)

Time into Shock	A.B. I	A.B. IV	A.B. VI	% shock
0	68.4	73.4	66.0	36
7 min	66.0			
15 min	63.5			
30 min	90.6			
1 hr	69.7			
2 hr	80.2			
3 hr	74.6			
4 hr	70.0			
5 hr	69.7			
0	71.2	67.4	51.8	73
7 min	63.3			
15 min	73.8			
30 min	68.9			
1 hr	62.5	70.1	73.9	
2 hr	69.9	67.8	-	
3 hr	69.5	63.7	74.3	
4 hr	65.7	63.4	61.4	
5 hr	-	57.9	59.6	
0	88.0	79.0	52.9	100
7 min	99.3			
15 min	71.4			
30 min	-			
1 hr	-	68.8	57.3	
2 hr	66.3	67.8	62.3	
3 hr	49.8	53.3	52.7	
4 hr	69.8	55.8	-	
5 hr	76.1	65.3	48.8	

TABLE C-10. OXYGEN UPTAKE (A.B. I) - SERIES OF SHORT SHOCKS - POTATO PROCESSING WASTE

Time	Oxygen Uptake (mg/1/hr)	Nature of Time Period Represented
10:25 a.m.	52.0	normal feed
10:45	68.5	normal feed
11:10	75.0	normal feed
11:30	67.5	zero time (normal feed)
11:45	68.1	shock I
12:00 noon	64.2	normal feed
12:18	66.6	shock II
12:34	67.2	normal feed
12:58	67.5	shock III
1:15	67.0	normal feed

Meat Processing--

Because of the large waste volumes required in this part of the project, a different meat processing industry was used as a source of waste from that employed in the laboratory shock tests. This plant reclaimed both blood and fats. The representative BOD level in this waste was approximately 800 mg/l. Shock load experiments were carried out in the same manner as those conducted with the potato processing waste. The operating parameters for the runs are given in Table C-11. Weather conditions precluded a third run. The resultant changes in DO are given in Table C-12.

Tables C-13 and C-14 list the oxygen uptakes determined for the three basins. The changes in the oxygen uptake in aeration basins do correspond to the directions of the changes in DO in the BioMonitor. In the first run (Table C-13), when the BioMonitor exhibited an increase in DO, the oxygen rate accordingly decreased from zero time through two hours. This increase in DO experienced a high BOD waste was attributed to the possibility of a disinfectant (from washing the plant floors) in the waste. The A.B. IV oxygen uptake exhibited a decrease from 2 through 4 hours. Peak time from the dye studies in aeration basin IV is 2.75 hours.

In the second run (Table C-14), the BioMonitor exhibited a decrease in DO as anticipated from the meat packing waste. The Aeration Basin I oxygen uptake increased from 20 minutes through 2 hours as anticipated from the DO change monitored both in the BioMonitor and in the basin itself.

A series of short shocks was again introduced using the meat packing

TABLE C-11. OPERATING PARAMETERS - MEAT PACKING WASTE - PILOT PLANT STUDY

	Run I 6/14/76		Run II 6/15/76	
Meat Packing* Flow, gal/min	0.65		1.2	
Baseline Feed* Flow, gal/min	1.1		0.5	
Return Sludge Flow, gal/min	3.5		3.5	
Solids	MLSS	MLVSS	MLSS	MLVSS
A.B. I	1938	1455	2562	1635
Return Sludge	2961	2016	3459	2160
Biomonitor	1496	1179	1551	1030

*Feed to Biomonitor unit is 20 ml/min sampled from the indicated combined Meat Packing waste and Baseline Feed flows. Retention time in the contact chamber is approximately 3 minutes.

TABLE C-12. ΔDO, MG/L IN BIOMONITOR, MEAT PROCESSING WASTES - PILOT PLANT STUDIES

	ΔDO, mg/l	
Time into Shock, minutes	Run I (6/14/76)	Run II (6/15/76)
4	± 0.80	- 0.06
8	± 1.20	- 0.30
10	± 1.25	
12		- 0.50
15		- 0.65

TABLE C-13. OXYGEN UPTAKE RATES (MG/L O_2/HR) - MEAT PACKING WASTE - PILOT PLANT STUDIES

6/14/76	A.B. 1	A.B. 4	A.B. 6
before	21.0	15.0	12.3
zero time	26.0		
7 min	26.2		
15 min	22.5		
30 min	21.2		
1 hr	19.8	16.2	15.0
2 hr	20.6	15.0	15.0
3 hr	25.5	14.7	14.2
4 hr	19.8	13.2	14.8
5 hr	20.0	13.6	13.6

TABLE C-14. OXYGEN UPTAKE RATES (MG/L O_2/HR) - MEAT PACKING WASTE - PILOT PLANT STUDIES

6/15/76	A.B. 1	A.B. 4	A.B. 6
before	20.1	15.0	15.4
zero time	27.0		
7 min	27.0		
20 min	25.8		
30 min	27.0		
1 hr	37.8		19.8
2 hr	51.0	18.0	17.7
3 hr	49.2	19.0	18.2
4 hr	46.5	19.5	18.0
5 hr	46.5	19.2	17.4

waste in an effort to correlate oxygen uptake and change in DO in the BioMonitor. In Table C-15 are the results of the oxygen uptake tests (from A.B. I) and in Table C-16 are the changes in DO (in BioMonitor unit) obtained during short shock runs II and IV. The oxygen uptakes were performed on samples taken from the first aeration basin after a 15 to 18 minute shock had been applied. These results are expected to be higher than those obtained after a similar period of normal feed flow. This is anticipated because of the high BOD of meat processing plant's waste. Examination of Table C-15 shows this not to be the case. The changes in DO level (Table C-16), however, do correctly correlate to the increase of BOD during shock loading and the relief of its removal. Table C-17 lists the TOC values obtained from shocking with the pilot plant with meat packing waste at 27.1% and 70.6%.

Again, this series of shock tests and the resultant data generated appear inconclusive. The reasoning is the same as previously discussed.

Electroplating Waste--

The source of this waste was a local electrographic company. Because of the solvents used in their processes the waste had an average TOC of 68 mg/l. The waste also contained zinc, copper, and nickel. Again the volume of waste required at the pilot plant necessitated the use of a different waste source from that employed in the laboratory testing.

During the three days of testing the return sludge was maintained at 3.5 gpm. The pilot plant feed flow was 1.6, 1.7, and 1.8 gpm. Shock loads were applied at the rate of 0.6, 0.6, and 1.75 gpm for percent of flow of 37.5, 35.3, and 97.2, respectively. The feed flow to the BioMonitor unit was 20 ml/min with a return flow rate of 120 ml/min.

Introduction of the electrographic waste into the system caused an initial increase in the DO level followed by a continuous decrease in DO. The shock test at the 37.5% level was aborted due to feed tube clogging at the 8 minute point. The results from the other two runs both display the behavior described. See Table C-18 for the actual ΔDO values.

The study employing the electroplating waste was also confused by the natural variations in the feed as discussed earlier. Nevertheless, both the oxygen uptake and TOC analyses were performed. The TOC data is seen in Table C-19. Again, no significant pattern was obtained. The data from the 35.3% level indicated a low point in TOC at the 15 minute sampling time in A.B. I. A significant decrease in TOC is seen in A.B. IV four hours later. The TOC in A.B. VI continues to drop one hour later (hour 5). From past experience and results, it is difficult to singly attribute these decreases to the electroplating waste. Moreover, this pattern is not accurately retained in the 97.2% data. Most significant is the fact that a decided decrease in TOC is again evidenced in A.B. I at the 15 minute sampling time.

The oxygen uptake data is reported in Table C-20. A correlation in data between direction of ΔDO and changes in oxygen uptake does exist for the 35.3% shock run but not for the 97.2% run. The DO increased in the 35.3% run through six minutes and then began decreasing. This correlates to the decrease in oxygen uptake from the zero time to 7 minute values and the in-

TABLE C-15. OXYGEN UPTAKE - SERIES OF SHORT SHOCKS MEAT PACKING WASTE - PILOT PLANT STUDIES

Description	Oxygen Uptake (mg/l/hr)
normal feed	53.1
normal feed	56.4
normal feed	54.6
normal feed	60.6
Shock I	58.2
normal feed	58.2
Shock II	60.0
normal feed	61.8
Shock III	60.3
normal feed	63.6
Shock IV	59.4
normal feed	61.2
Shock V	41.4

TABLE C-16. ΔDO, MG/L - SERIES OF SHORT SHOCKS MEAT PACKING WASTE - PILOT PLANT STUDIES

Shock II	ΔDO
Time into shock, min	
4	-0.05
8	-0.08
12	-0.17
Time out of shock, min	
4	+0.05
8	+0.14
12	+0.16
Shock IV	
Time into shock, min	
18	-0.20
Time out of shock, min	
14	+0.10

TABLE C-17. TOC VALUES (MG/L) - MEAT PROCESSING WASTE - PILOT PLANT STUDIES

Time into Shock	A.B. I	A.B. IV	A.B. VI	% Shock
0	58.0	48.6	56.1	37.1
7 min	54.9			
15 min	52.7			
30 min	71.2			
1 hr	62.4	61.2	49.5	
2 hr	81.0	52.7	43.3	
3 hr	85.7	49.7	54.9	
4 hr	52.2	62.4	48.6	
5 hr	52.9	49.7	47.6	
0	56.9	52.2	36.1	70.6
7 min	81.2			
15 min	52.2			
30 min	48.8			
1 hr	99.4	69.0	74.4	
2 hr	99.4	42.1	82.7	
3 hr	103.1	39.5	75.6	
4 hr	110.4	69.0	61.5	
5 hr	110.4		47.6	

TABLE C-18. ΔDO, MG/L, IN BIOMONITOR - ELECTROPLATING WASTES - PILOT PLANT STUDY

Time into Shock minutes	% Shock Load	
	35.3%	97.2%
0	0	0
2	+0.05	+0.10
4	+0.15	+0.10
6	+0.20	+0.05
8	+0.05	-0.20
10	-0.35	-0.40
12	-0.40	-0.60
15	-0.55	-0.65

TABLE C-19. TOC VALUES (MG/L) - ELECTROPLATING WASTE - PILOT PLANT STUDY

Time into Shock	A.B. I	A.B. IV	A.V. VI	% Shock
0	59.1	56.5	50.2	35.3
7 min	47.9			
15 min	38.3			
30 min	41.3			
1 hr	48.1	46.2	46.4	
2 hr	60.5	45.4	44.8	
3 hr	47.5	42.2	45.4	
4 hr	48.5	27.5	42.2	
5 hr	47.7	-	39.5	
0	53.0	50.2	57.7	97.2
7 min	58.4			
15 min	49.5			
30 min	66.8			
1 hr	67.5	58.4	60.7	
2 hr	70.1	58.1	60.2	
3 hr	65.6	60.0	69.6	
4 hr	60.9	60.5	60.7	
5 hr	64.9	50.2	55.8	

TABLE C-20. OXYGEN UPTAKE DATA (MG/L/HR) - ELECTROPLATING WASTE - PILOT PLANT STUDY

Time into Shock	A.B. I	A.B. IV	A.B. VI	% Shock
before	25.5	14.7	24.8	35.3
0	26.7			
7 min	26.1			
15 min	27.8			
30 min	25.5			
1 hr	28.2	24.0	23.2	
2 hr	36.8	25.8	24.4	
3 hr	50.4	23.1	24.3	
4 hr	79.0	20.7	21.4	
5 hr	63.8	rained out		
before		27.2	22.5	97.2
0	54.3			
7 min	57.3			
15 min	51.0			
30 min	33.0			
1 hr	29.4	25.0	26.4	
2 hr	28.0	21.4	23.1	
3 hr	42.6	21.9	18.0	
4 hr	25.5	20.4	20.9	
5 hr	36.8	19.5	20.2	

crease in oxygen uptake from the 7 minute to 15 minute sampling value. The 97.2% run shows an increase from 0 to 7 minutes in the oxygen uptake and a decrease in the value from 7 to 15 minutes. Again, however, it is questionable whether some of these differences are significant given the level of precision of the test procedure.

Although the pilot plant studies produced sparse results which could not be predicted or reproduced, the experience essentially began the on-site testing. An idea for sensitivity of response to raw sewage, maintenance regimes, operating problems, field needs, etc. was obtained. In Section 6 the results of the on-site trials are presented. This represents BioMonitor response due to inherent variability in the sewage - not industrial waste overlays.

APPENDIX D

ON-SITE INFORMATION

MAINTENANCE PROCEDURES - INDUSTRIAL SITE

1) Upon arriving, note any peculiarities on strip chart (e.g., poor mixing in main reactor, floating solids in clarifier).
2) Note time, date, and location on strip chart. Note temperature in monitor tube.
3) Take solids sample from main reactor (contact chamber also as necessary).
4) Measure return flow from monitor tube and note on strip chart and daily log.
5) Switch feed to waste position; measure total feed rate and raw feed rate; note on strip chart and daily log.

6) Plug overflow tubing in clarifier; plug (or clamp) return tubing from monitor tube; remove DO probe; quickly plug probe opening.
7) Clean DO probe membrane (replace if necessary) and begin calibration.
8) Remove strip chart from previous day's operation and check recorder for ink supply, paper supply and pen operation.
9) Check pump head tubing; replace if necessary.
10) Clean feed tubing, if necessary, by backwashing with propanol followed by plain water.
11) Check oil level in air compressor.
12) Skim solids from top of clarifier and stir if necessary.
13) Check air diffuser for clogging. Unclog if necessary.
14) Waste solids as needed.
15) Clean up BioMonitor and station.
16) Complete DO probe calibration; note temperature on strip chart; and reinsert probe (replacing teflon tape as necessary); fill in data required in log.
17) Remove plugs (clamp) from return tubing from monitor tube and from overflow tubing in clarifier.
18) Measure total feed flow and raw feed flow and note on strip chart and daily log.
19) Measure return flow and note on strip chart and daily log.
20) Note time, date, and location on strip chart.
21) Fill dilution water tank as needed.

MAINTENANCE PROCEDURES - WASTE TREATMENT SITE

1) Upon arriving, note any peculiarities on strip chart (e.g., poor mixing in main reactor, floating solids in clarifier).

2) Note time, date, and location on strip chart.
3) Take solids sample from main reactor (contact chamber also, if necessary).
4) Measure return flow from monitor tube and note on strip chart and daily log.
5) Switch feed to waste position; measure feed flow rate; and note on strip chart and daily log.
6) Plug overflow tubing in clarifier; plug return tubing from monitor tube; remove DO probe; plug probe opening.
7) Clean DO probe membrane (replace if necessary) and begin calibration.
8) Remove strip chart from previous day's operation and check recorder for ink supply, paper supply and pen operation.
9) Check pump head tubing; replace if necessary.
10) Clean feed tubing, if necessary. Backwash with bleach followed by excess water.
11) Replace desiccant air supply. Save used desiccant for regeneration.
12) Skim solids from top of clarifier. Stir main reactor every 2 hours.
13) Check air diffuser for clogging. Unclog if necessary.
14) Waste solids as needed.
15) Clean up BioMonitor and station.
16) Complete DO probe calibration; note temperature on strip chart; reinsert probe (replacing teflon tape as necessary in Monitor tube).
17) Remove plugs from return tubing from monitor tube and from overflow tubing in clarifier.
18) Measure feed flow and note on strip chart and daily log.
19) Measure return flow and note on strip chart and daily log.
20) Note time, date, and location on strip chart.

BIOMONITOR DAILY LOG

Location: ______________________ By: ______________________

Date: __________ Day __________ Time: ______________________

I. BioMonitor

A. Solids: MLSS __________ MLVSS ______ % MLVSS:MLSS __________

B. Clarification __________

C. Air Supply: Desiccant Replaced __________ Main Reactor Setting ____

Monitor Tube Setting ________

D. Flow Rates: Feed ______________ Return ____________________

E. Feed Tubing: Backwash ________ Clean ________ Replace __________

F. Mixed Liquor Wasted: ____________________

G. Temperature in Monitor Tube: ____________ Time: __________

H. General Housekeeping:

II. D.O. Meter

A. Calibration: Adjustment (±) ________________

B. Membrane: Replace ______________________

III. Chart Recorder

A. Ink: Refill ______________ C. Paper: Refill ______________

B. Pen: Clean ______________ D. Calibration: Adjustment(±) ______

IV. Pumps

A. Replace Pump Head Tubing: ________________

B. Approximate Vari-speed Seeting: ____________

V. Other

DATA SAMPLING ROUTINE - WASTE TREATMENT PLANT

I TOC Samples

1) Composite separately 50 ml grab samples of both influent and effluent every 20 minutes every hour.
2) Keep composite acidic from first grab sample on - check with pH paper.
3) At end of one hour, shake, and then filter composite into test tube.
4) Seal.
5) Label with date, time, the letter "C" (for composite), location and source, e.g.,

10-4-76
3-4 pm C
Location

6) Store in refrigerator.
7) If recorder indicates a "shock" take an influent grab sample - DO NOT COMPOSITE - as often as warranted - e.g., every 15 minutes instead of a composite.
8) Acidify, filter, seal, label (as shown) and store:

10-4-76	date
4:25 pm S	time, "S" for shock
Influent	location
Sharp Decrease	nature of shock

9) This applies only to the influent during a shock. Plant effluent is still composited.

II O_2 Uptake

1) One analysis per hour from specified location in aeration basin.
2) Record temperature in bottle after O_2 uptake is complete.
3) Label chart paper with data, time of sample withdrawn and temperature. Indicate periodically the correct time on the chart paper by placing an arrow on the line with the time next to it.

DATA SAMPLING ROUTINE - INDUSTRIAL SITE

I TOC Samples

1) Take 50 ml grab samples of influent every 20 minutes. Composite 3 samples (150 mls) every hour.
2) Keep composite acidic from first grab sample on - check with pH paper.
3) At end of one hour, shake composite, then filter composite into beaker.
4) Pipet 2 ml of filtrate into clean test tube.
5) Pipet 2 ml of water into the same test tube.
6) Seal.
7) Shake.
8) Label with date, time, the letter "C" (for composite), location, e.g.,:

10-4-76
LOCATION
3-4 pm C

9) Store in refrigerator.
10) If recorder indicates a "shock" take a grab sample - DO NOT COMPOSITE - as often as warranted - e.g., every 15 minutes instead of a composite.
11) Acidify, filter, dilute, seal, label (as shown below) and store.

10-4-76	date
4:25 pm S	time, "S" for shock
Industrial Site	location
Sharp Decrease	nature of shock

II Metals Samples (Site 2)

1) Fill two 30 ml test tubes with an aliquot from the composite for metals analyses.
2) Acidify.
3) Label as indicated in I-8.
4) Seal.

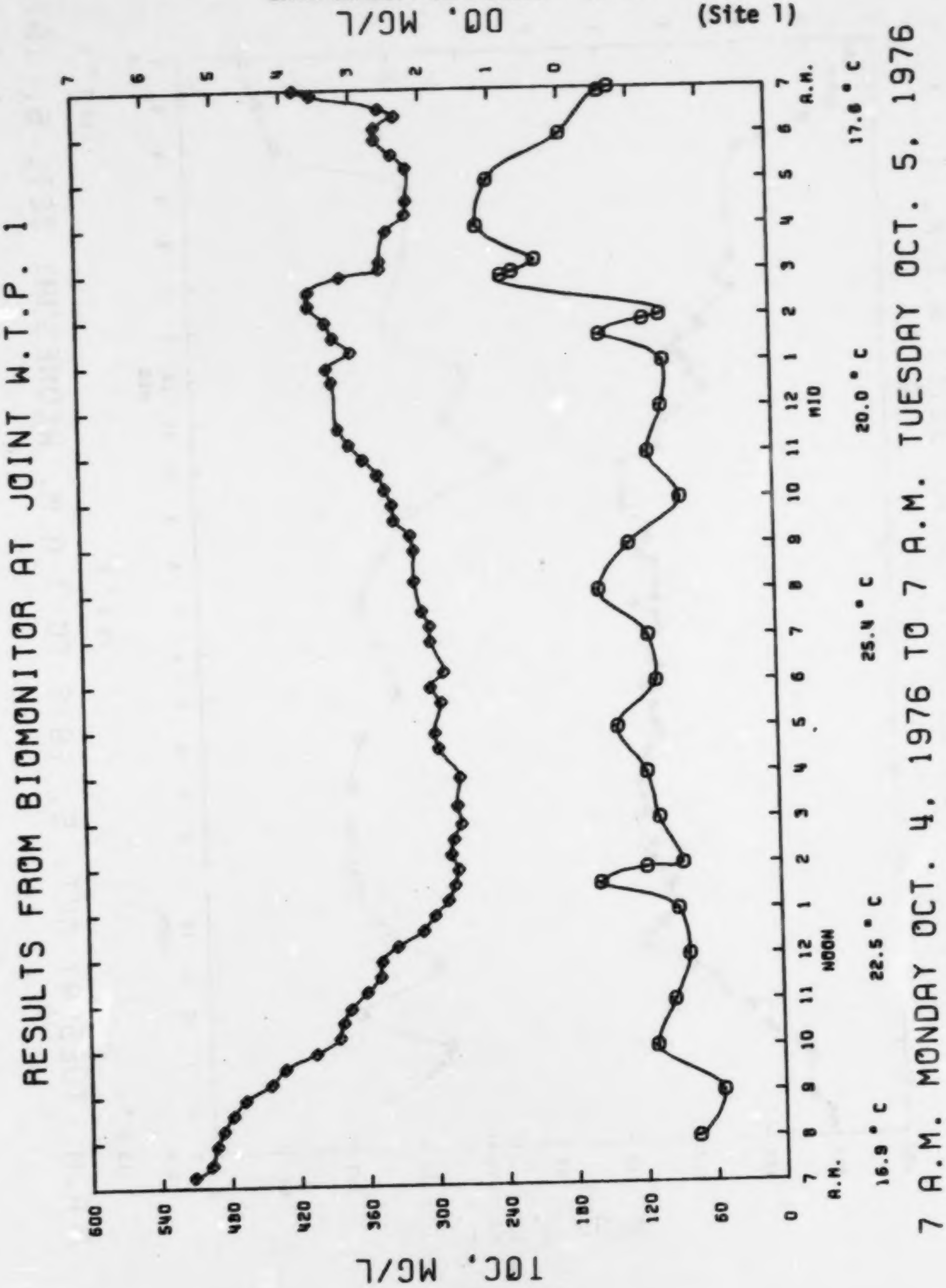
III Recording pH Meter (Site 1)

1) Keep eye on recording pH meter.
2) Periodically record time on chart.
3) If rapid major change occurs, take a grab sample of influent for TOC analysis as listed in Steps I-10 and I-11.

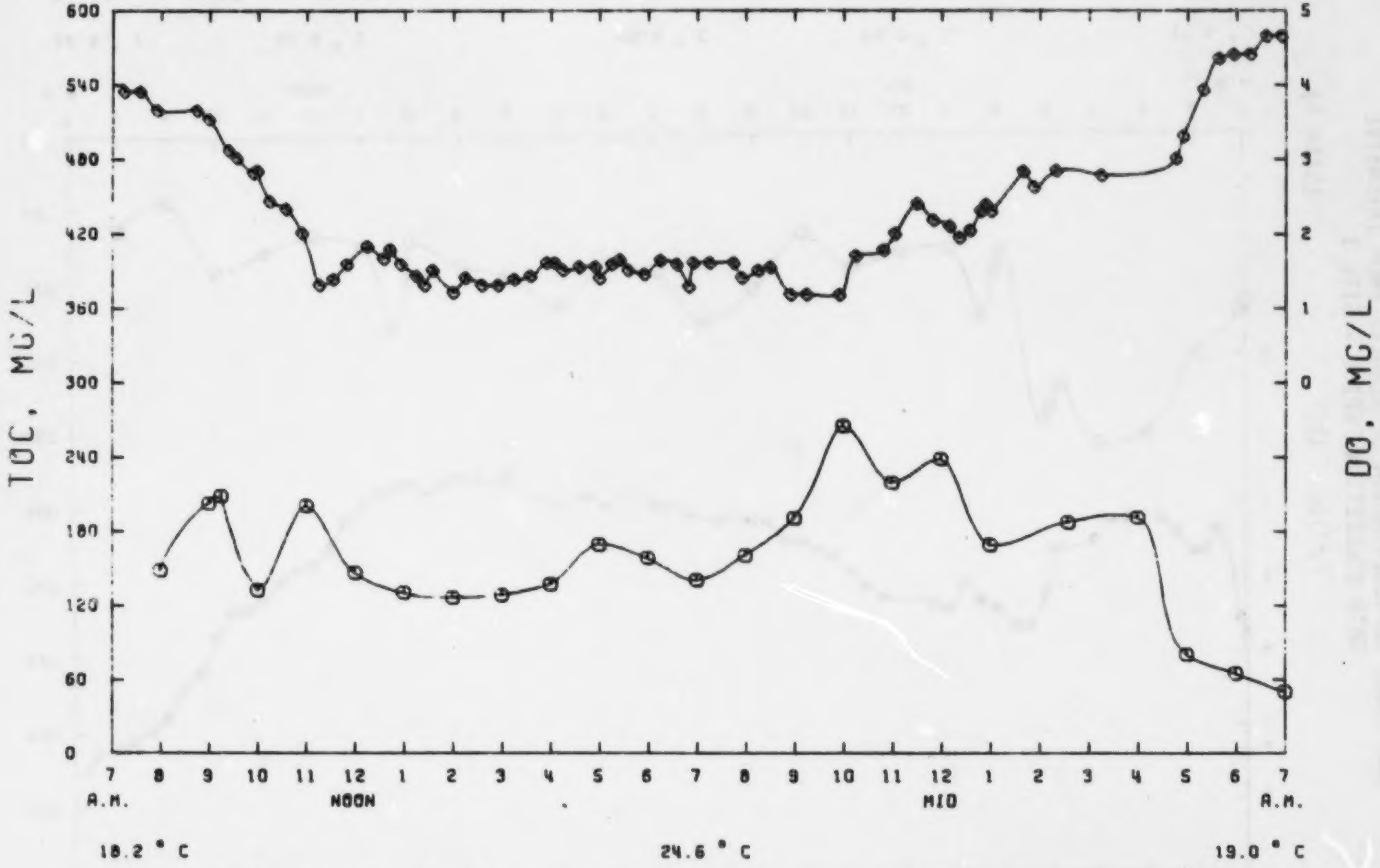
Indicate periodically the correct time on the chart paper by placing an arrow on the line with the time next to it.

APPENDIX E
GRAPHICAL REPRESENTATION OF RESULTS FROM INTENSIVE DATA COLLECTION PERIOD - SITE 1

(Site 1)

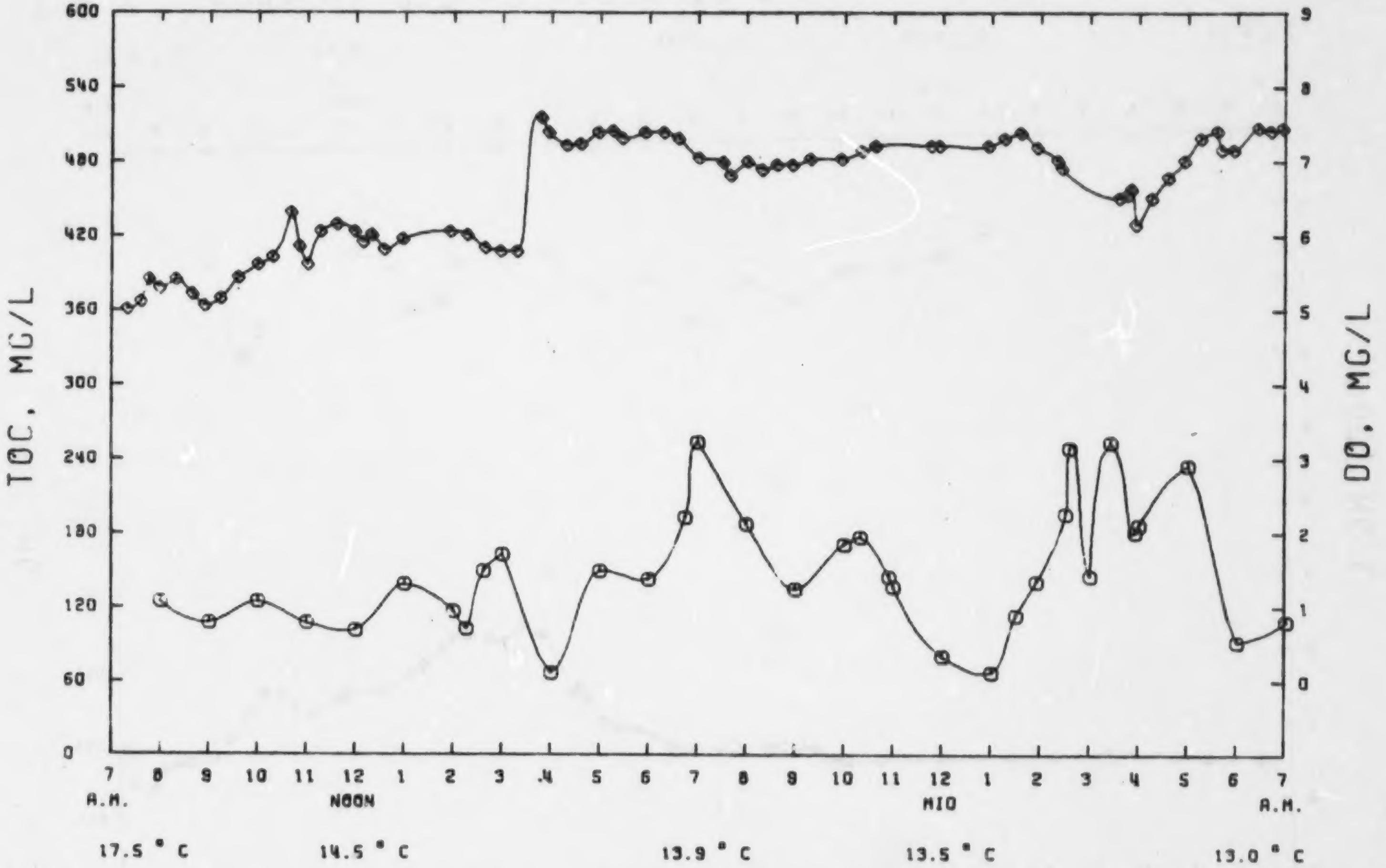


RESULTS FROM BIOMONITOR AT JOI[illegible] W.T.P. 1



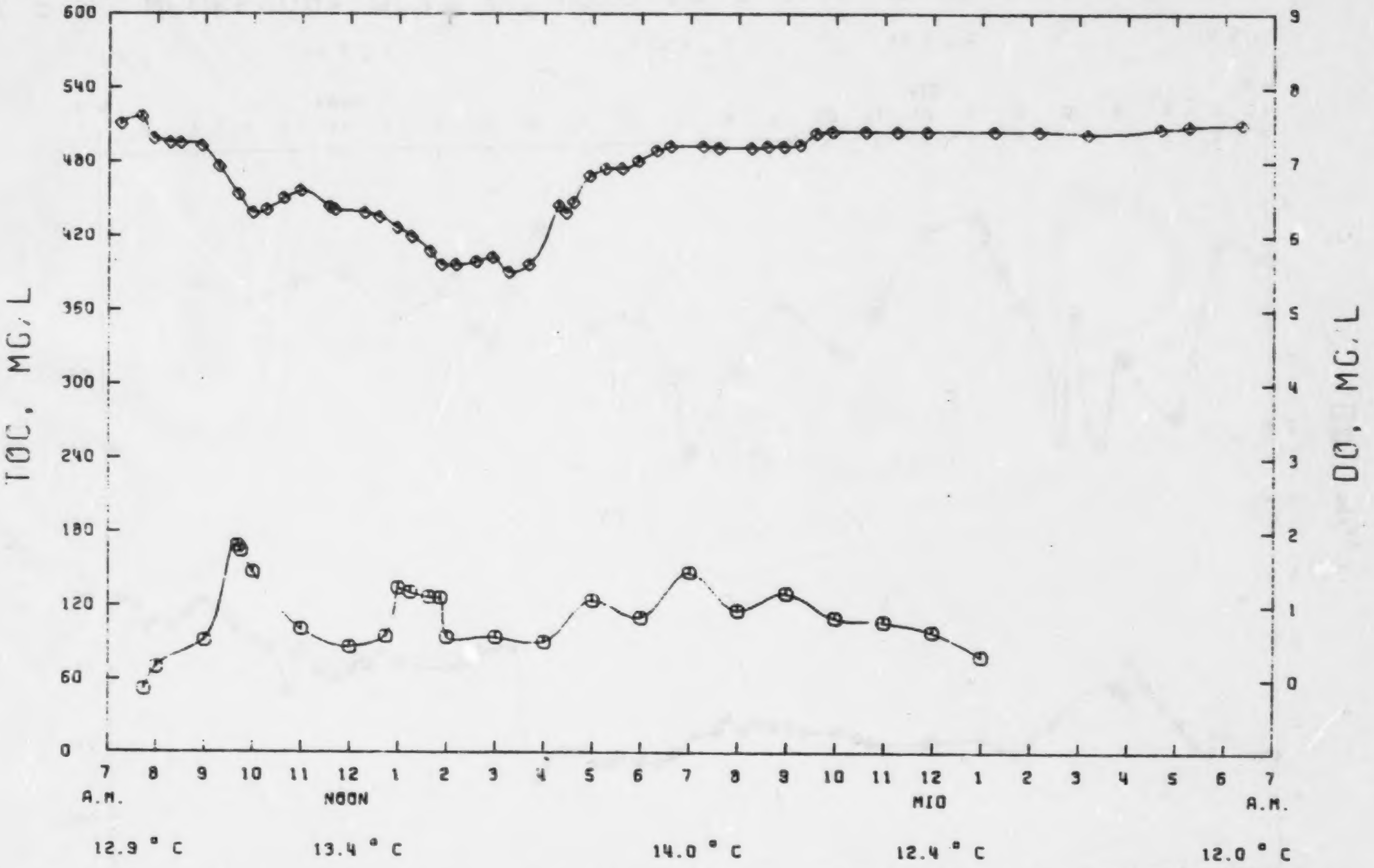
7 A.M. TUESDAY OCT. 5, 1976 TO 7 A.M. WEDNESDAY OCT. 6, 1976

RESULTS FROM BIOMONITOR AT JOINT W.T.P. 1



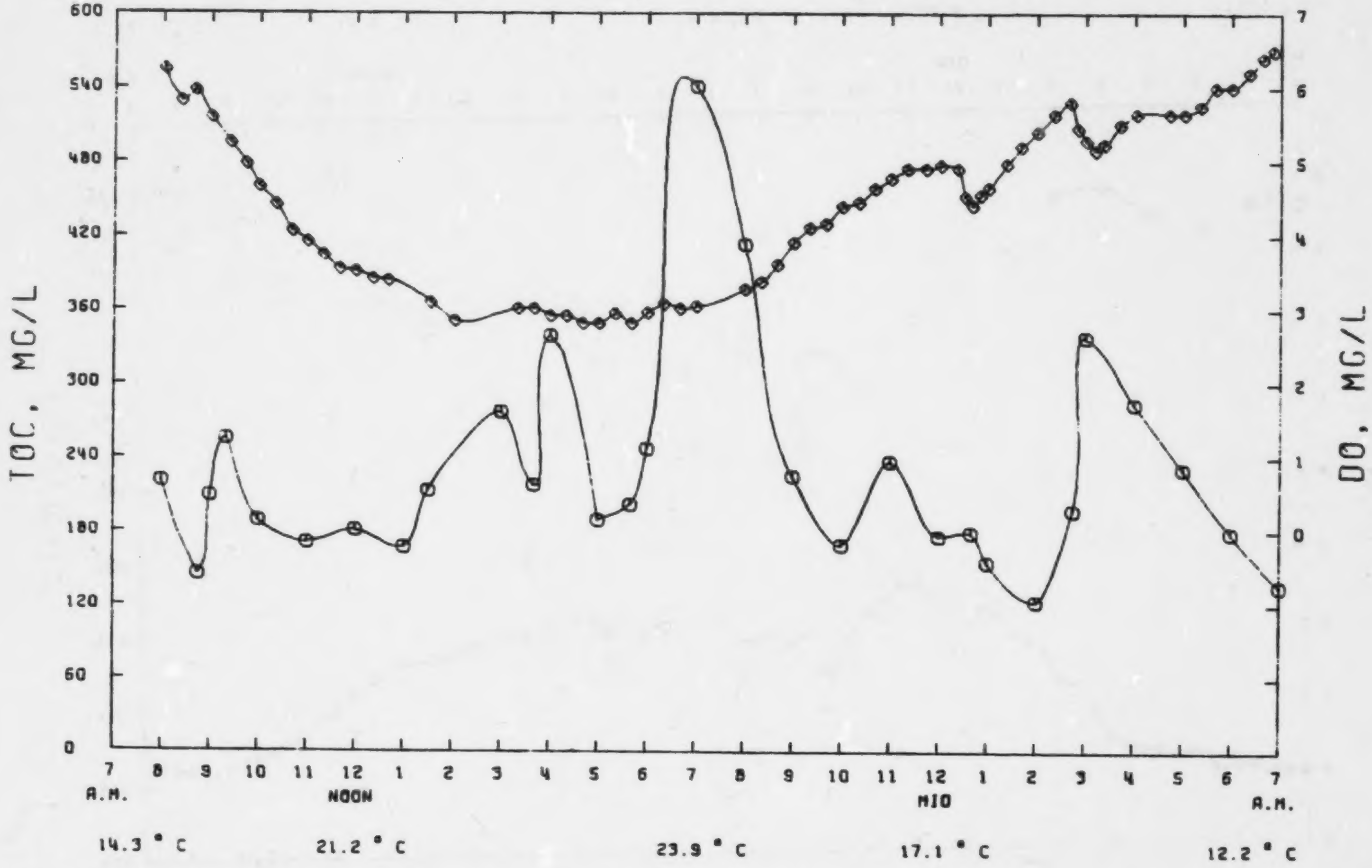
7 A.M. WEDNESDAY OCT. 6, 1976 TO 7 A.M. THURSDAY OCT. 7, 1976

RESULTS FROM BIOMONITOR AT JOINT W.T.P. 1



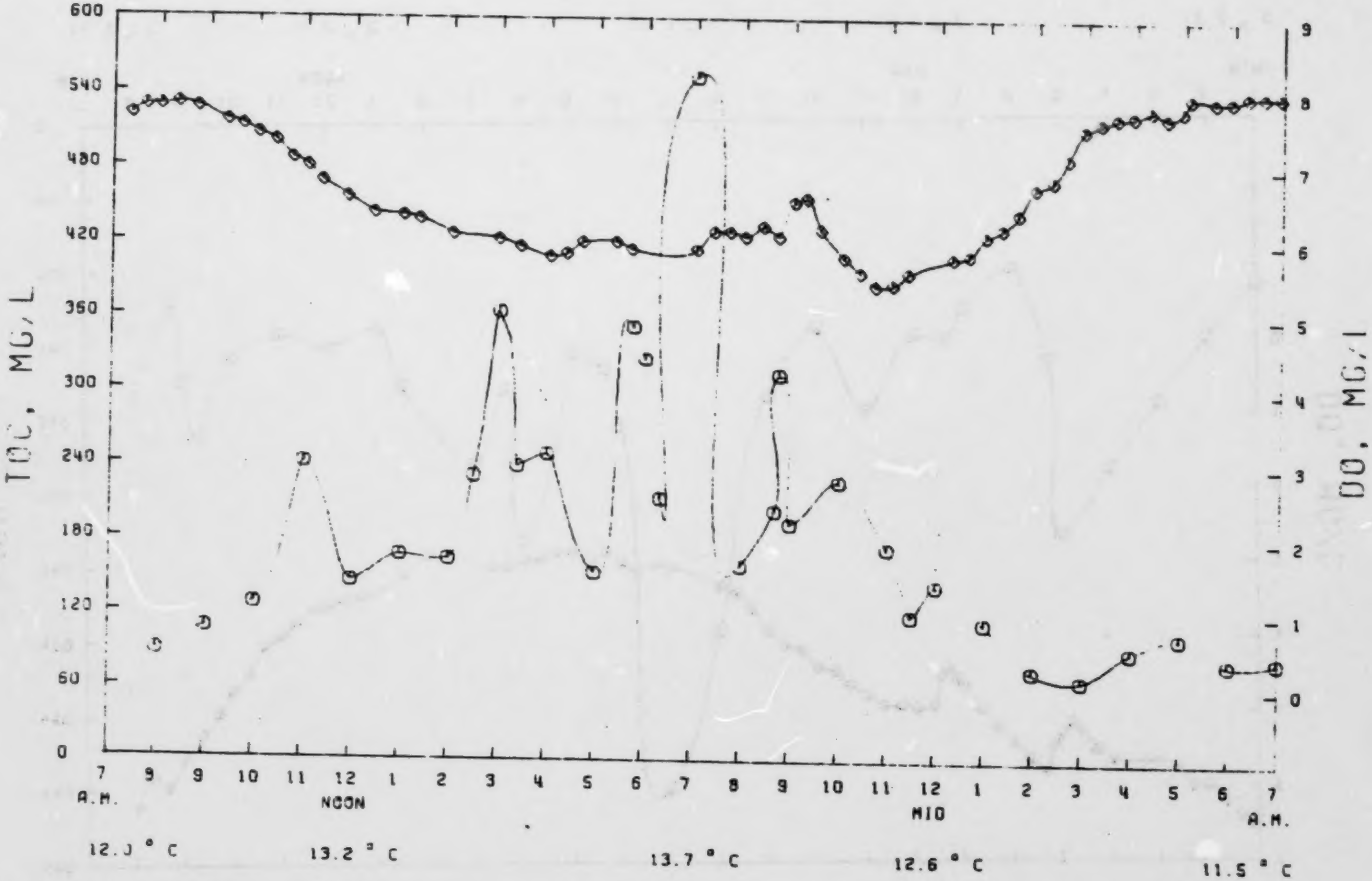
7 A.M. THURSDAY OCT. 7, 1976 TO 7 A.M. FRIDAY OCT. 8, 1976

RESULTS FROM BIOMONITOR AT JOINT W.T.P. 1



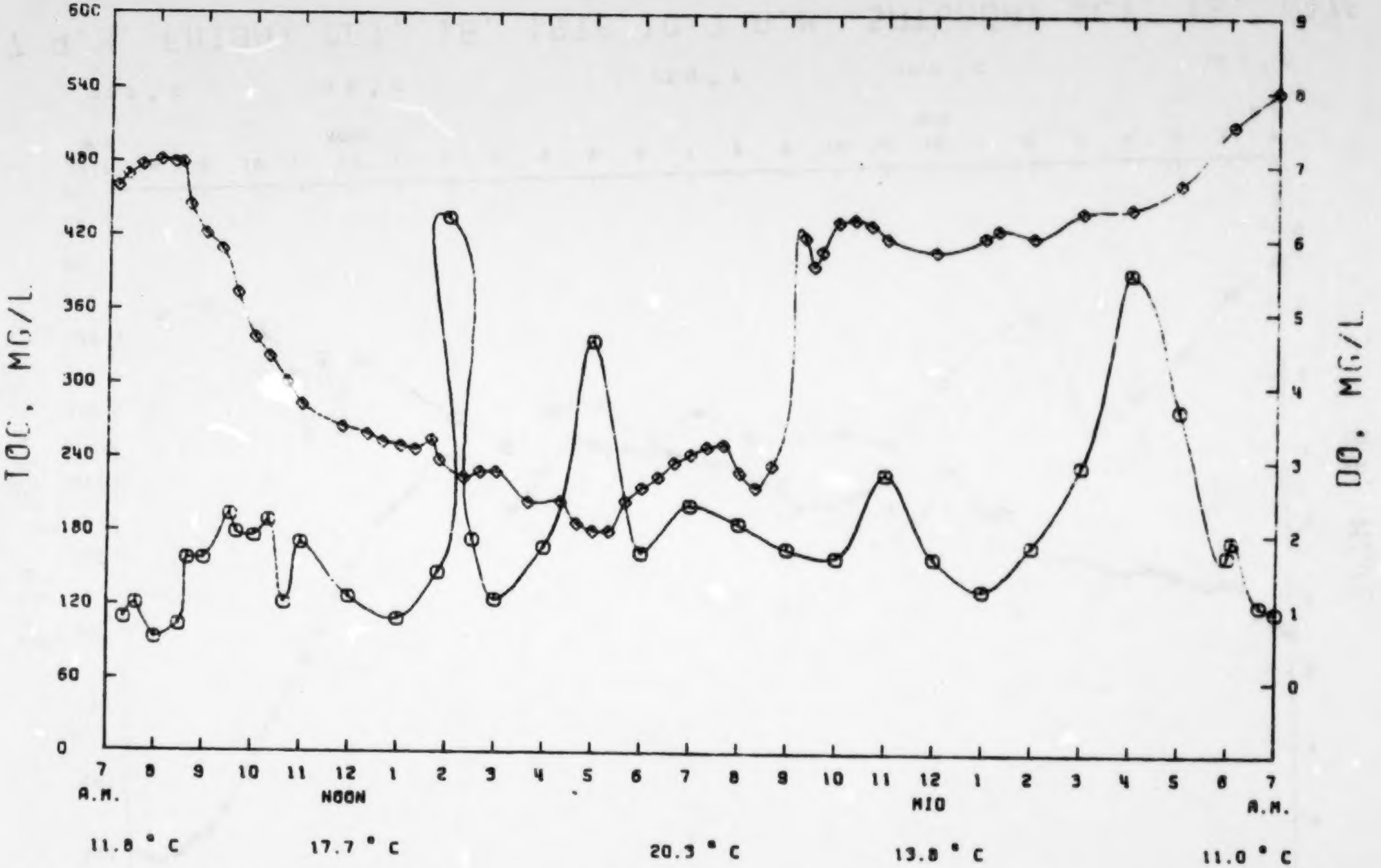
7 A.M. WEDNESDAY OCT. 13, 1976 TO 7 A.M. THURSDAY OCT. 14, 1976

RESULTS FROM BIOMONITOR AT JOINT W.T.P. 1



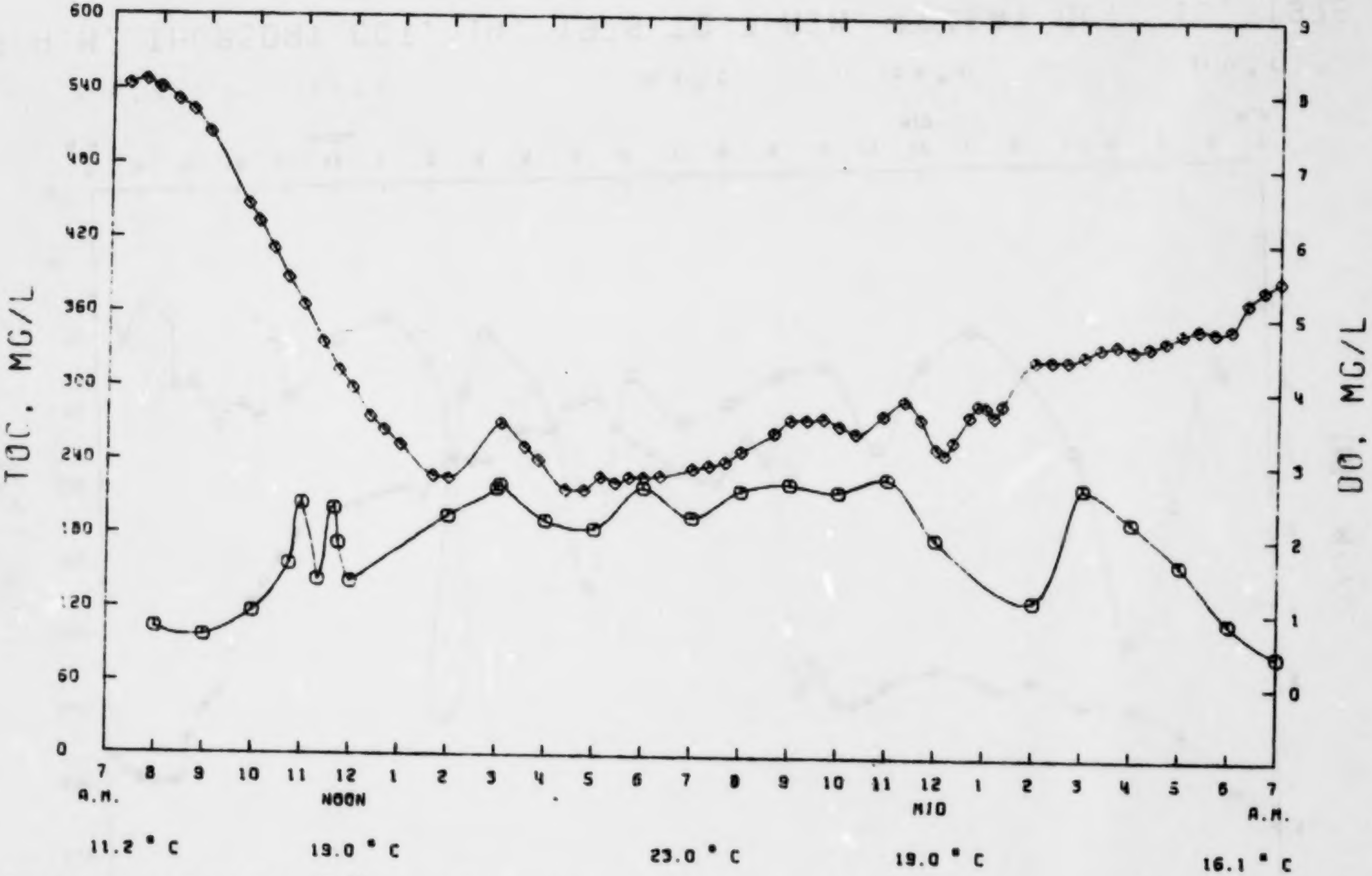
7 A.M. FRIDAY OCT. 8, 1976 TO 7 A.M. SATURDAY OCT. 9, 1976

RESULTS FROM BIOMONITOR AT JOINT W.T.P. 1



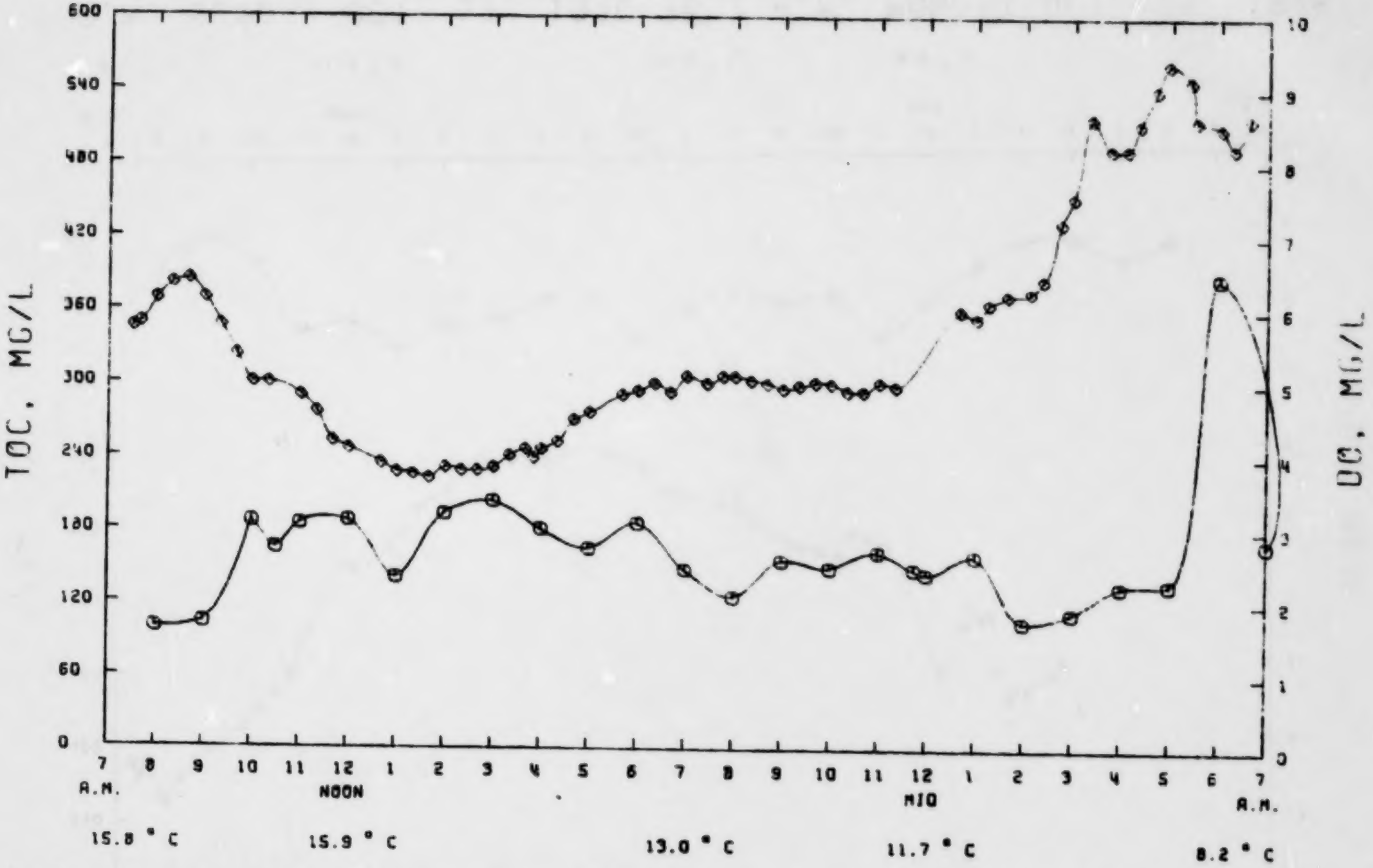
7 A.M. THURSDAY OCT. 14. 1976 TO 7 A.M. FRIDAY OCT. 15. 1976

RESULTS FROM BIOMONITOR AT JOINT W.T.P. 1



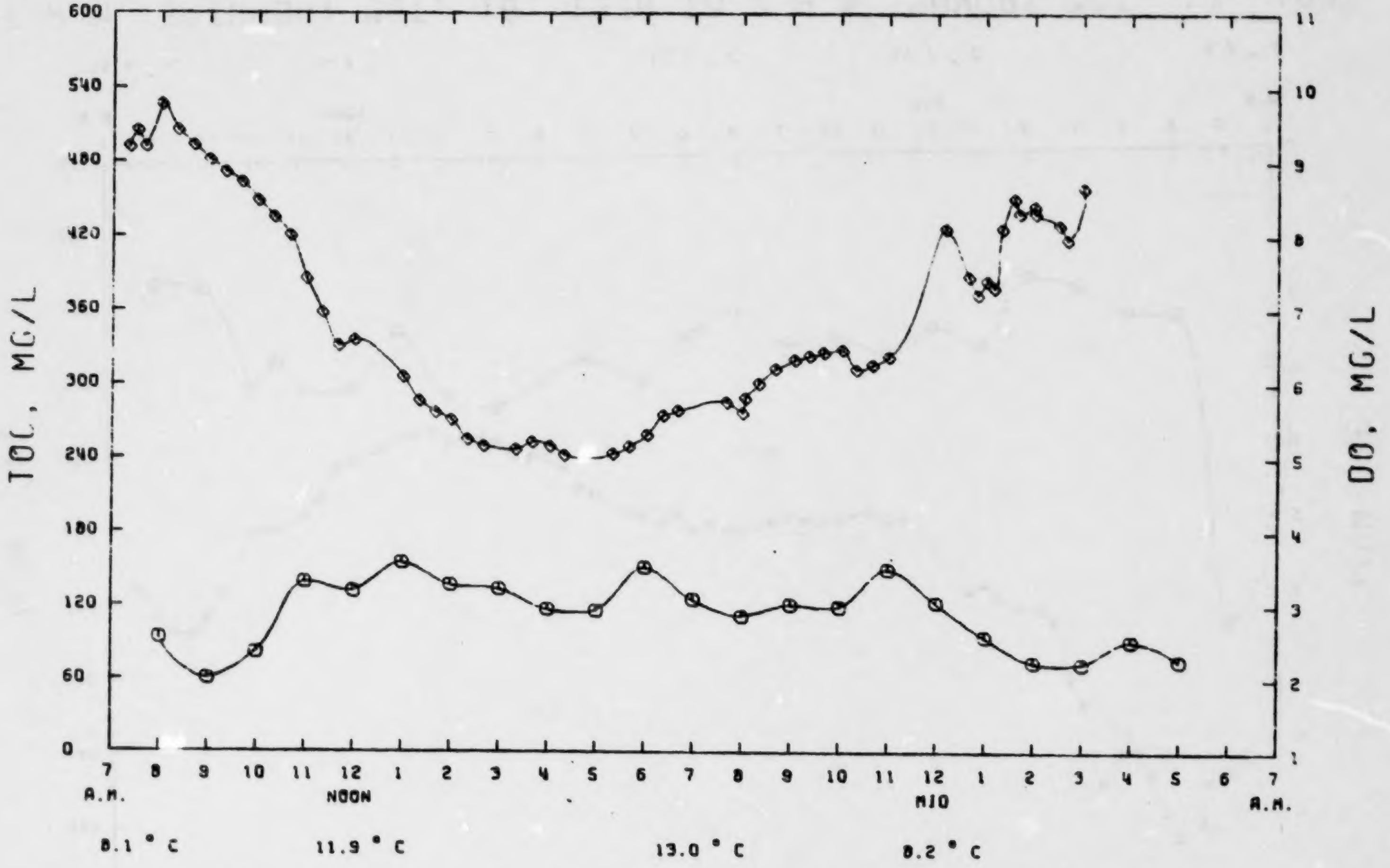
7 A.M. FRIDAY OCT. 15, 1976 TO 7 A.M. SATURDAY OCT. 16, 1976

RESULTS FROM BIOMONITOR AT JOINT W.T.P. 1



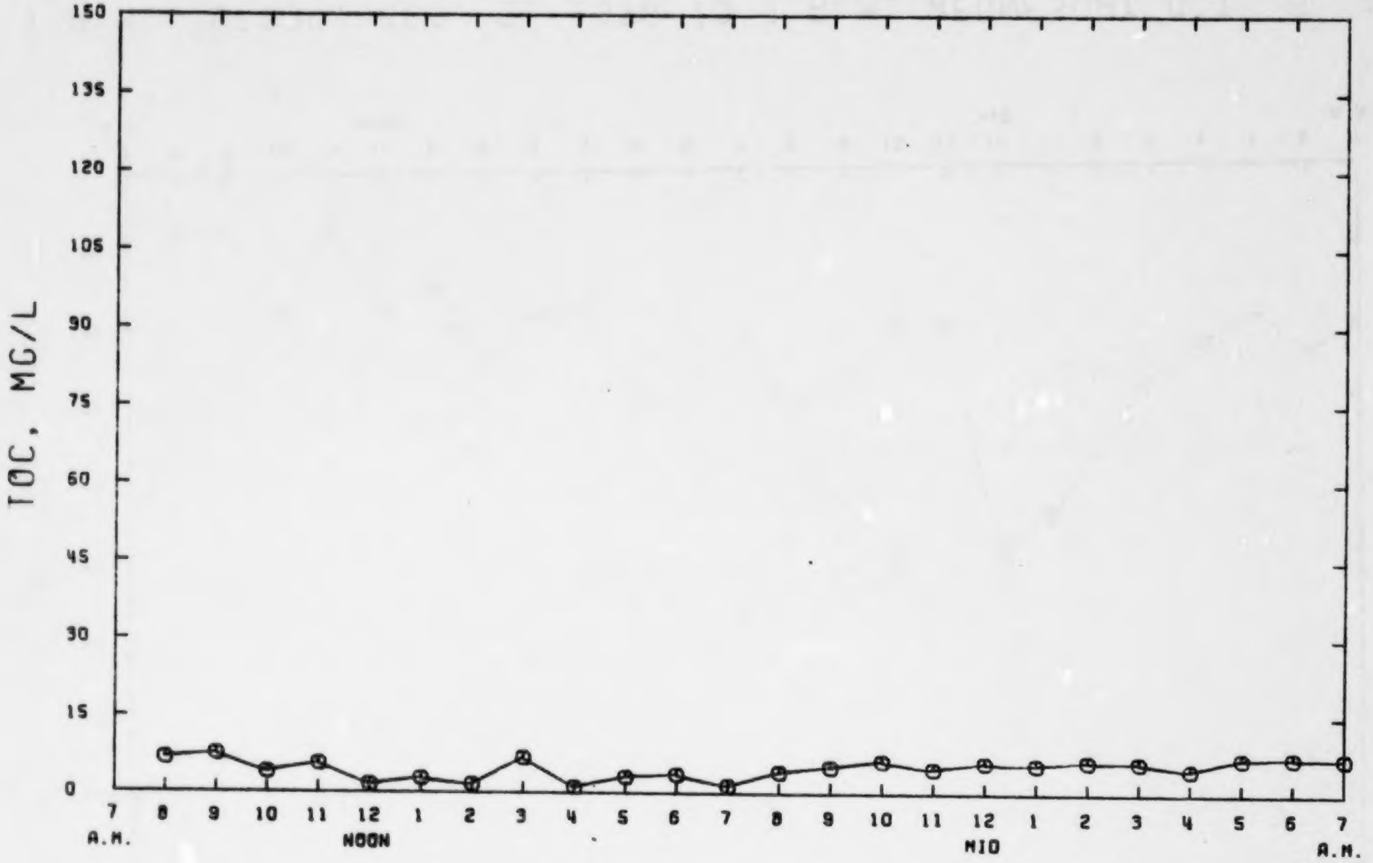
7 A.M. SATURDAY OCT. 16, 1976 TO 7 A.M. SUNDAY OCT. 17, 1976

RESULTS FROM BIOMONITOR AT JOINT W.T.P. 1



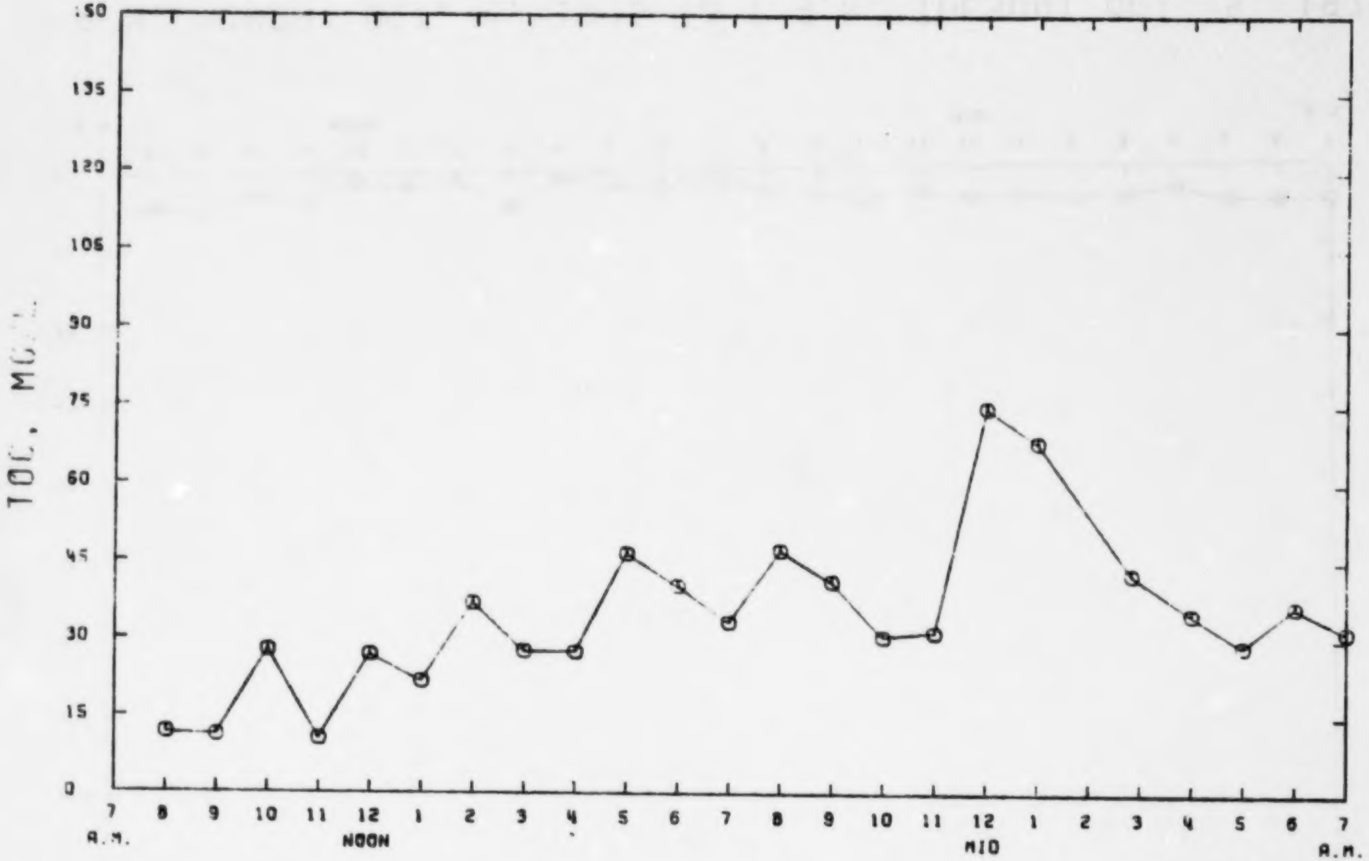
7 A.M. SUNDAY OCT. 17, 1976 TO 7 A.M. MONDAY OCT. 18, 1976

EFFLUENT CONCENTRATION AT JOINT W.T.P. 1



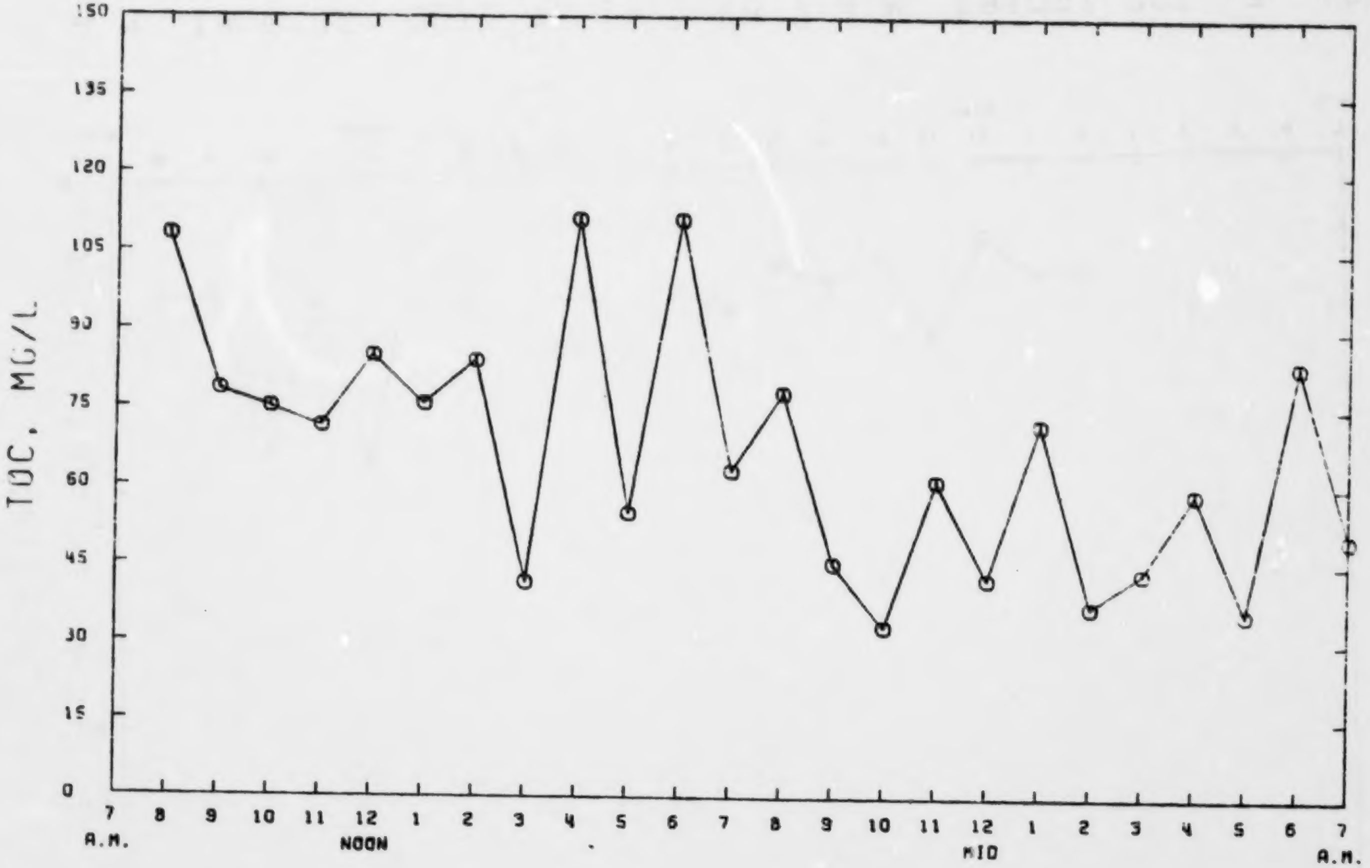
7 A.M. MONDAY OCT. 4, 1976 TO 7 A.M. TUESDAY OCT. 5, 1976

EFFLUENT CONCENTRATION AT JOINT W.T.P. 1



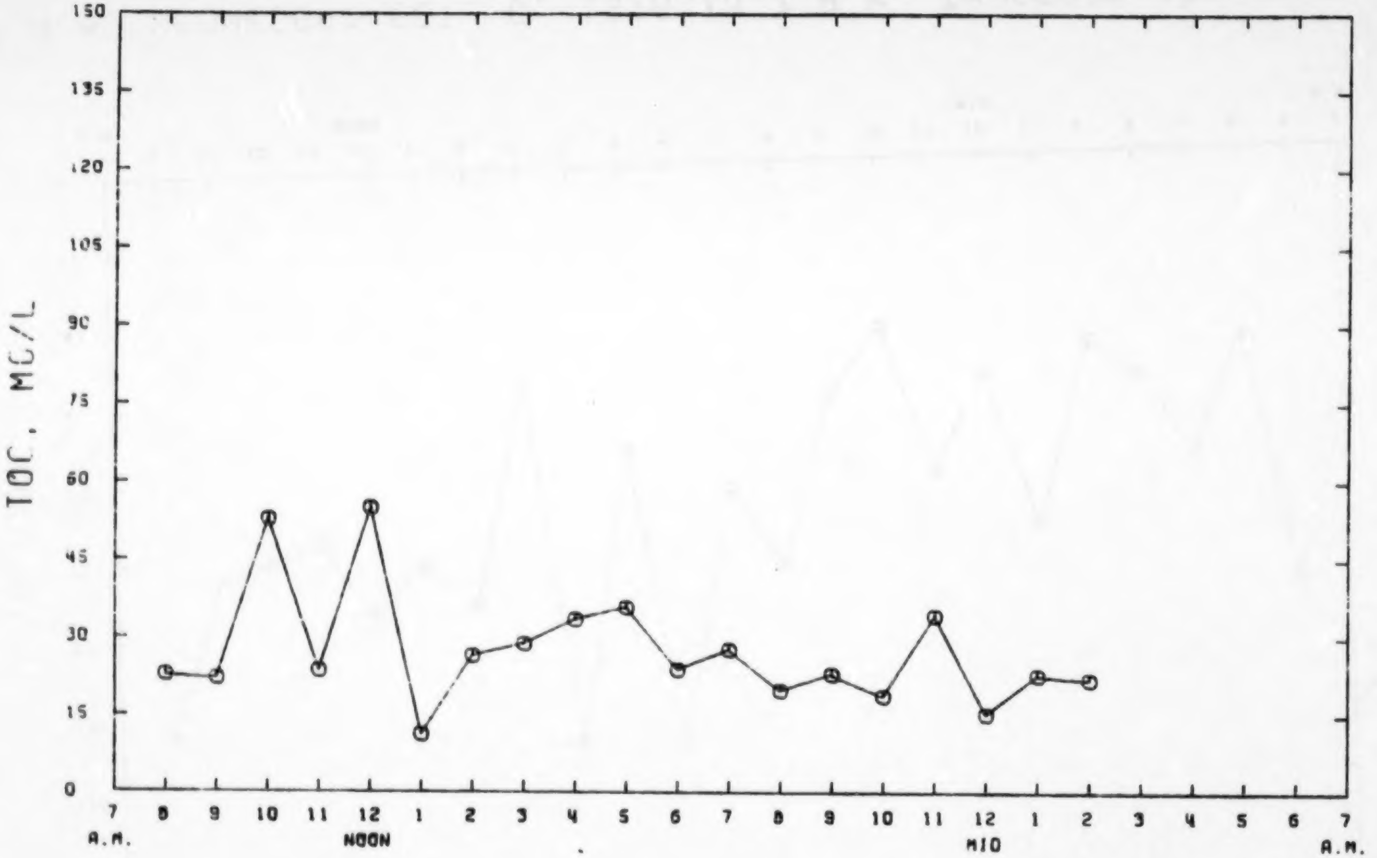
7 A.M. TUESDAY OCT. 5, 1976 TO 7 A.M. WEDNESDAY OCT. 6, 1976

EFFLUENT CONCENTRATION AT JOINT W.T.P. 1



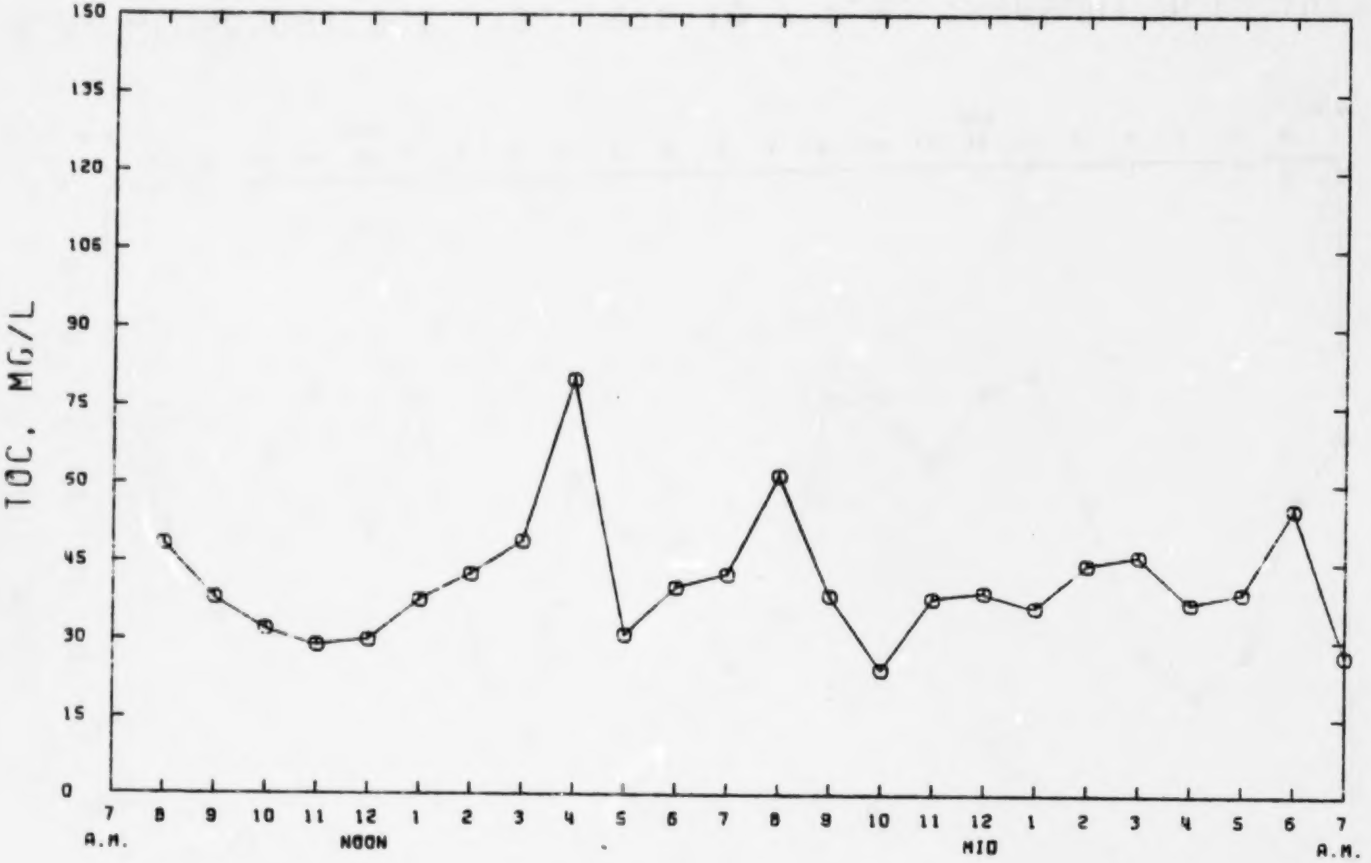
7 A.M. WEDNESDAY OCT. 6, 1976 TO 7 A.M. THURSDAY OCT. 7, 1976

EFFLUENT CONCENTRATION AT JOINT W.T.P. 1



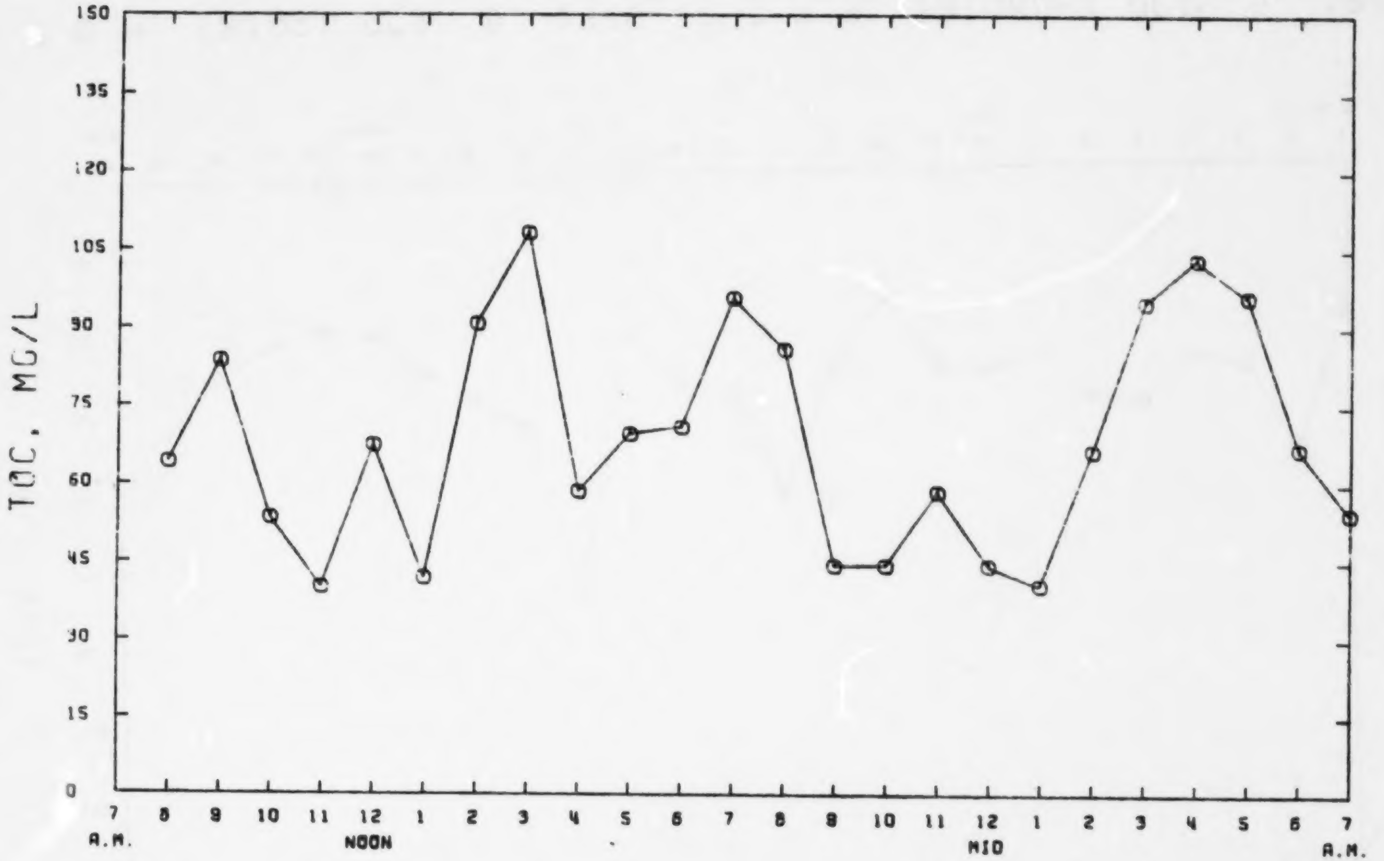
7 A.M. THURSDAY OCT. 7, 1976 TO 7 A.M. FRIDAY OCT. 8, 1976

EFFLUENT CONCENTRATION AT JOINT W.T.P. 1



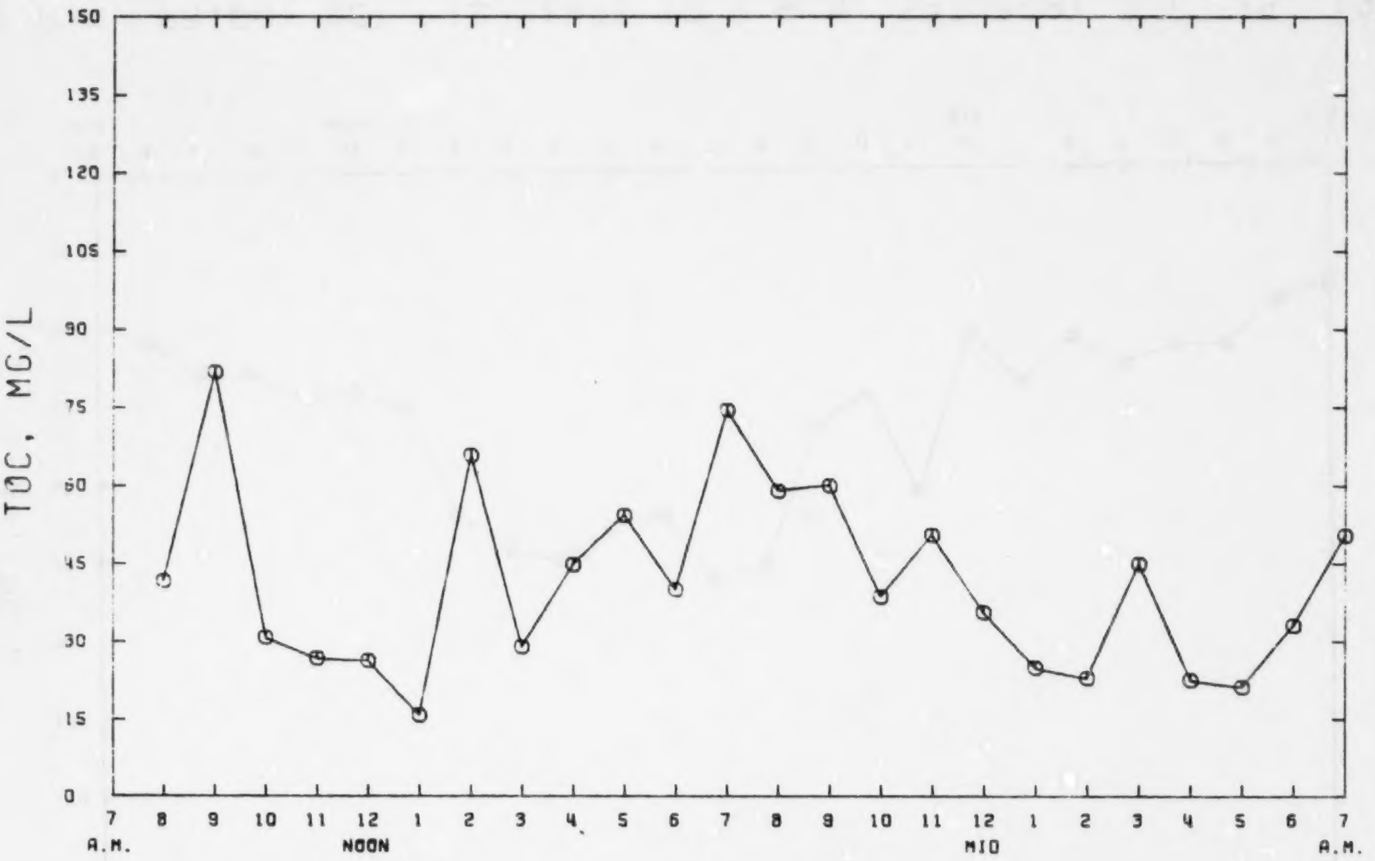
7 A.M. FRIDAY OCT. 8, 1976 TO 7 A.M. SATURDAY OCT. 9, 1976

EFFLUENT CONCENTRATION AT JOINT W.T.P. 1



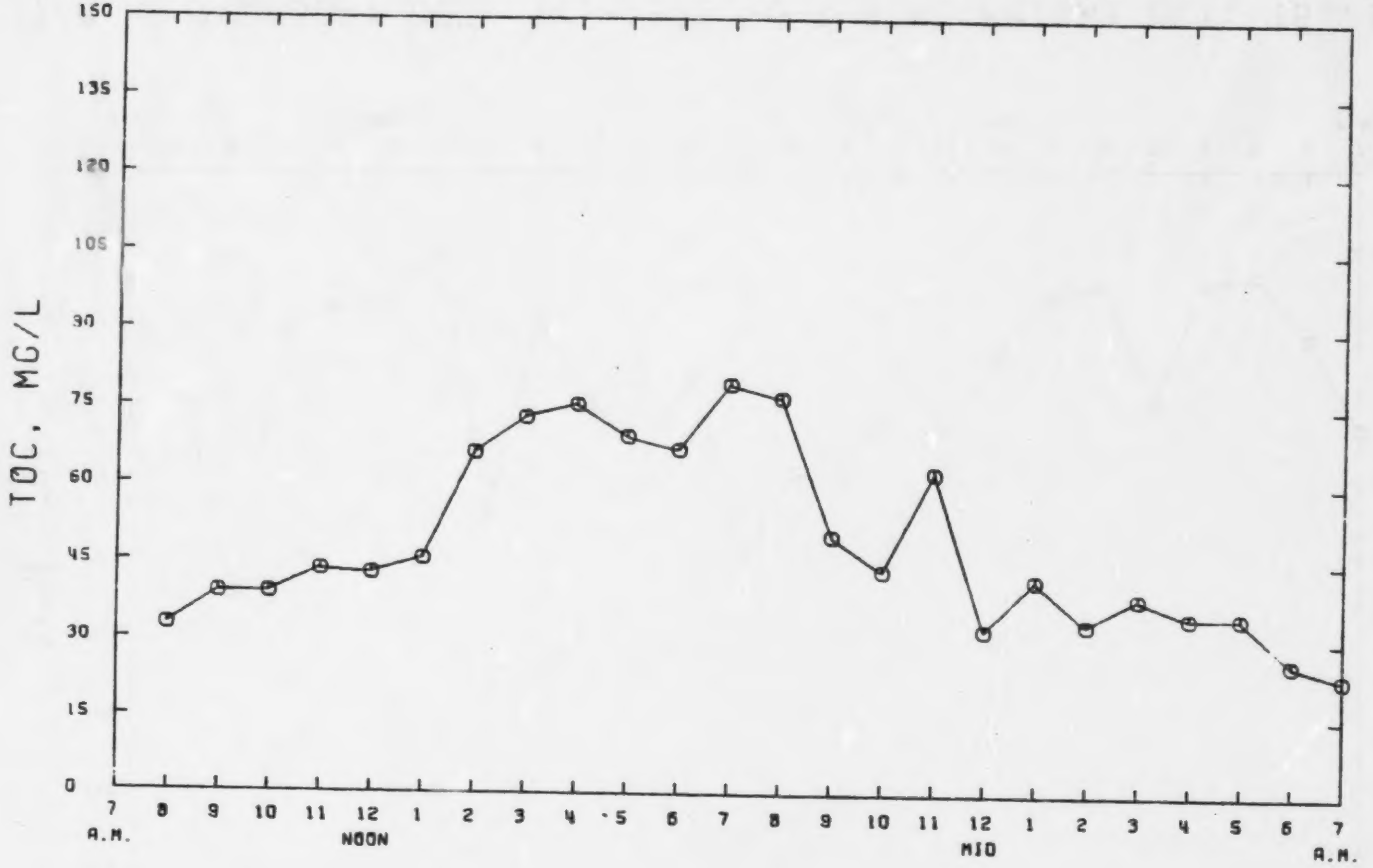
7 A.M. WEDNESDAY OCT. 13, 1976 TO 7 A.M. THURSDAY OCT. 14, 1976

EFFLUENT CONCENTRATION AT JOINT W.T.P. 1



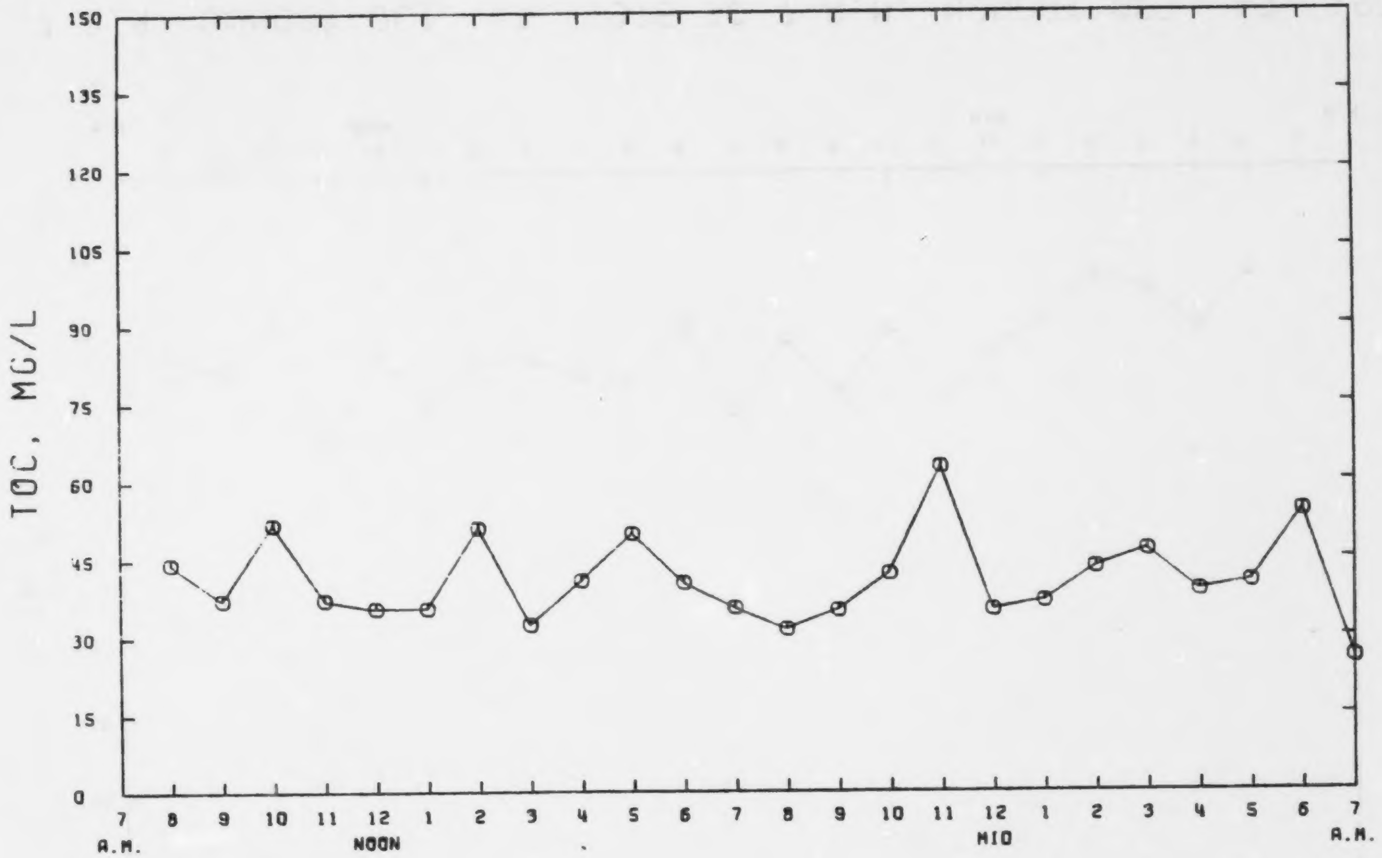
7 A.M. THURSDAY OCT. 14, 1976 TO [illegible] A.M. FRIDAY OCT. 15, 1976

EFFLUENT CONCENTRATION AT JOINT W.T.P. 1

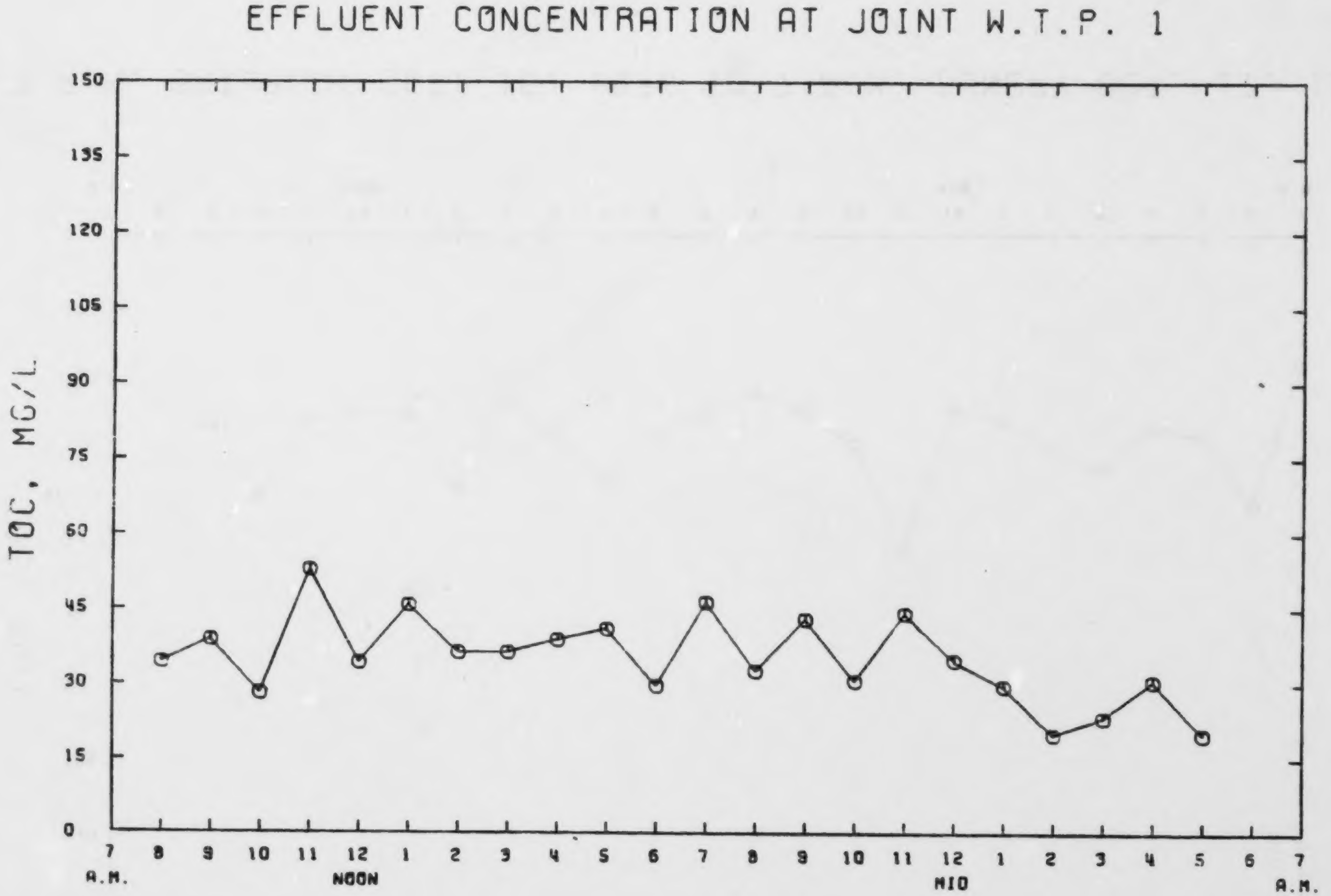


7 A.M. FRIDAY OCT. 15, 1976 TO 7 A.M. SATURDAY OCT. 16, 1976

EFFLUENT CONCENTRATION AT JOINT W.T.P. 1

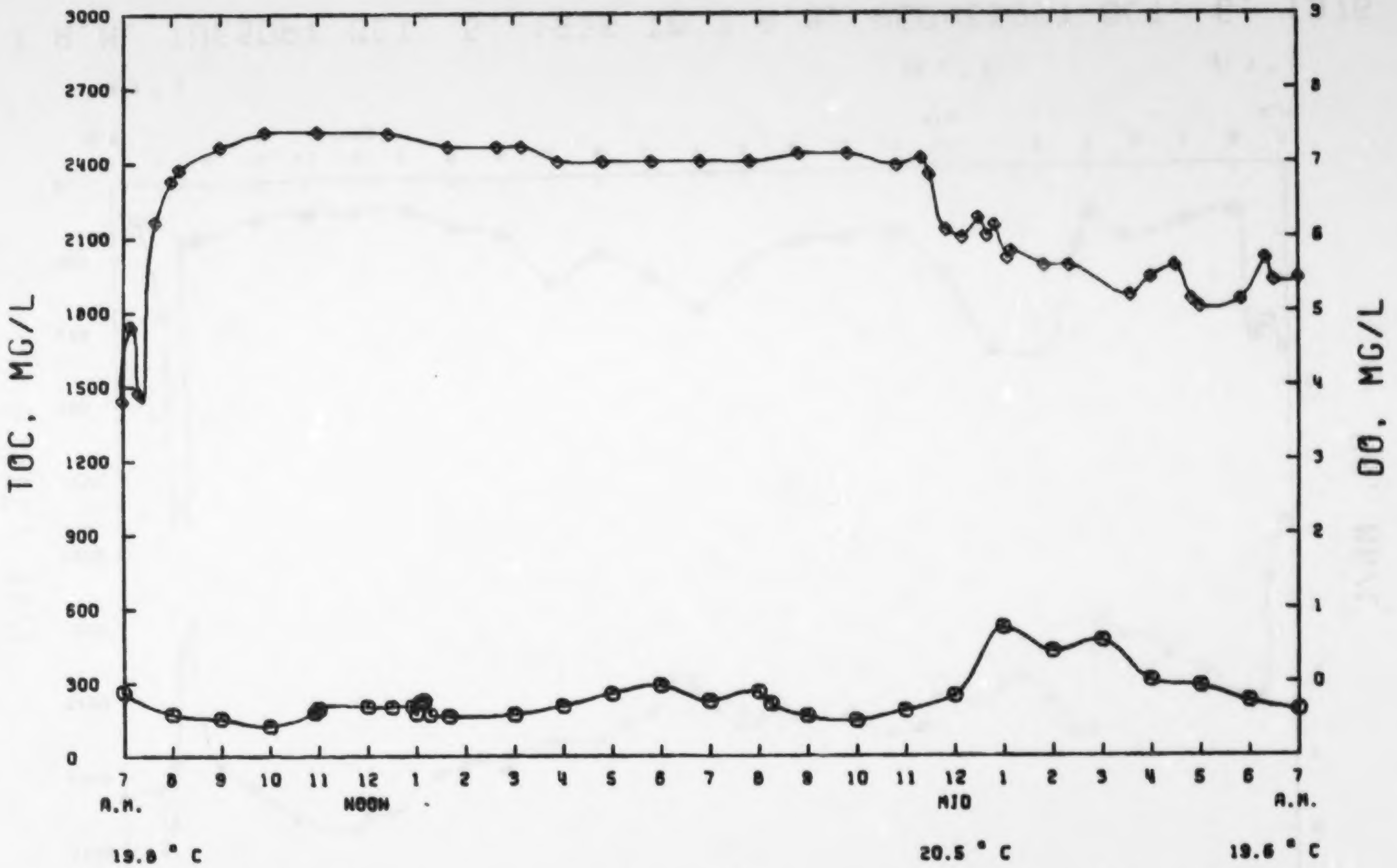


7 A.M. SATURDAY OCT. 16, 1976 TO 7 A.M. SUNDAY OCT. 17, 1976



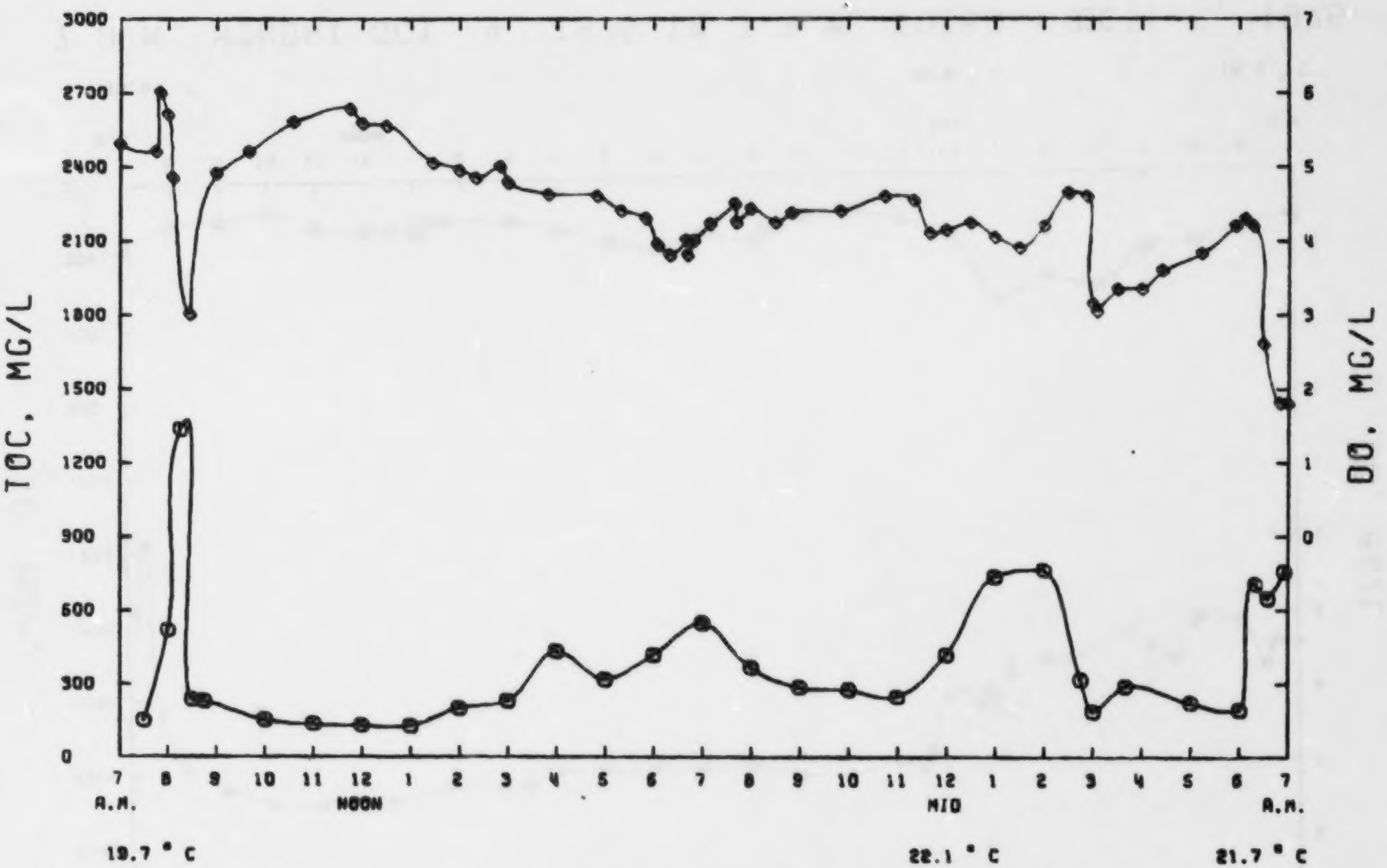
7 A.M. SUNDAY OCT. 17, 1976 TO 7 A.M. MONDAY OCT. 18, 1976

RESULTS FROM BIOMONITOR AT INDUSTRIAL SITE 1



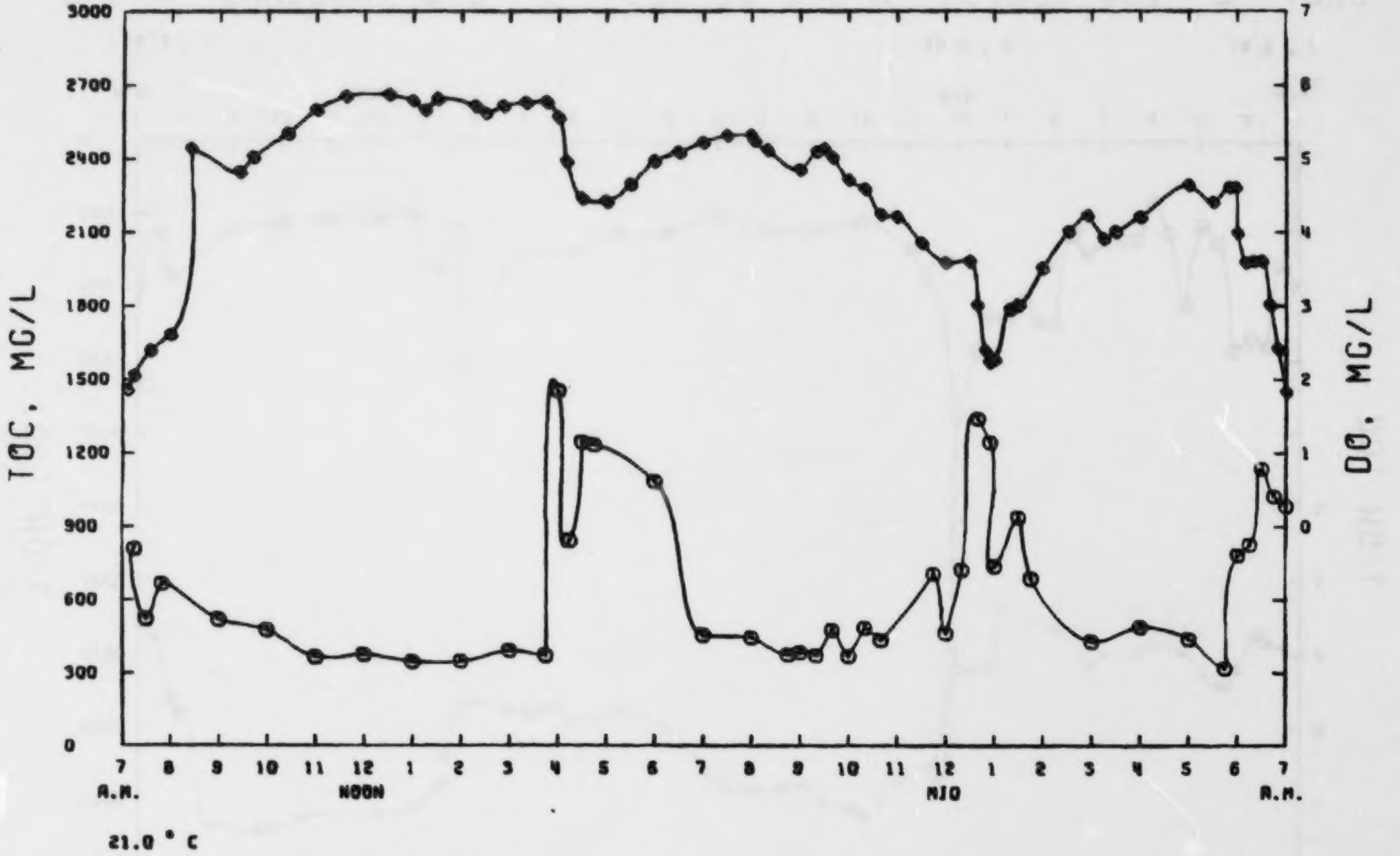
7 A.M. MONDAY OCT. 4, 1976 TO 7 A.M. TUESDAY OCT. 5, 1976

RESULTS FROM BIOMONITOR AT INDUSTRIAL SITE 1

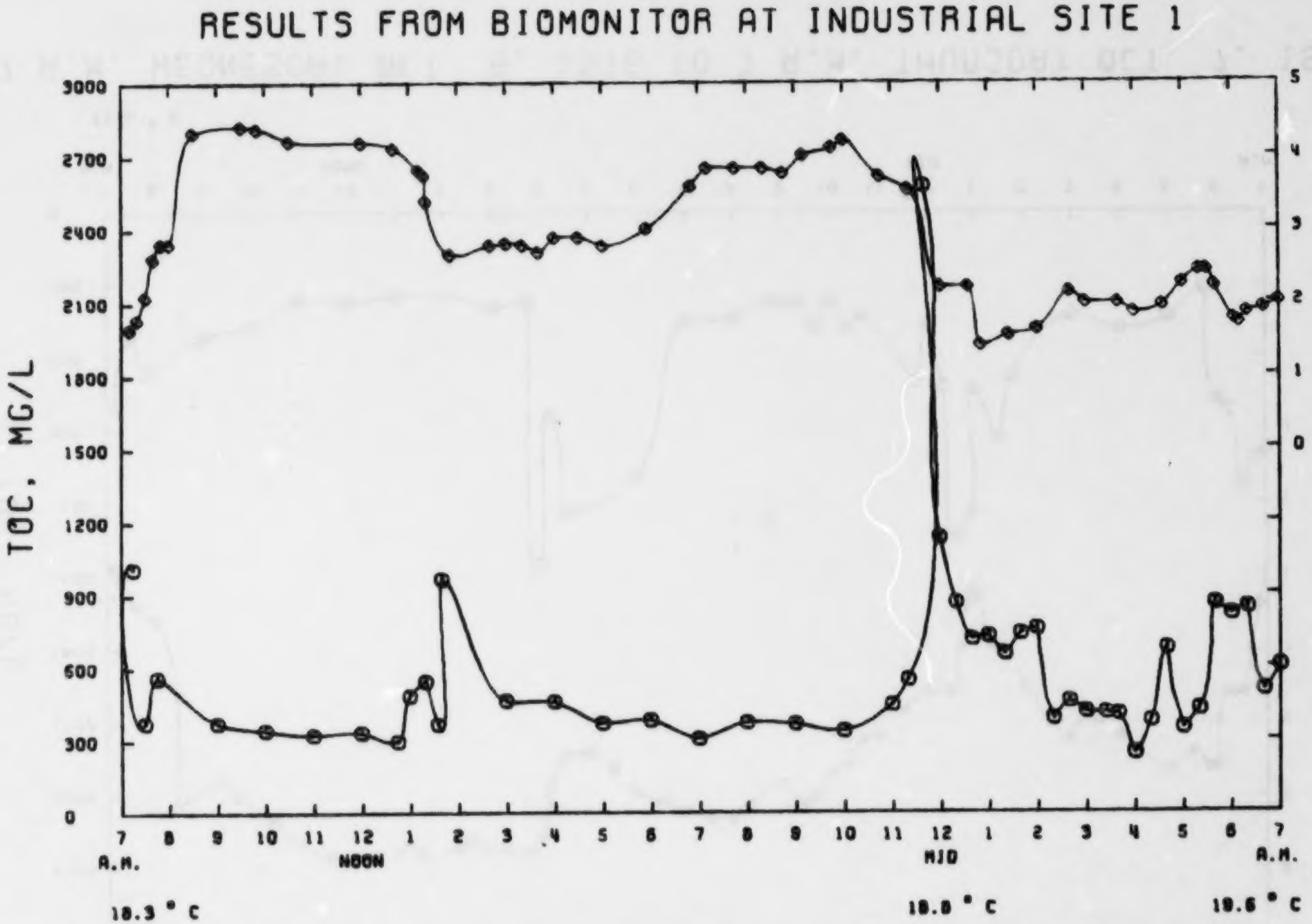


7 A.M. TUESDAY OCT. 5, 1976 TO 7 A.M. WEDNESDAY OCT. 6, 1976

RESULTS FROM BIOMONITOR AT INDUSTRIAL SITE 1



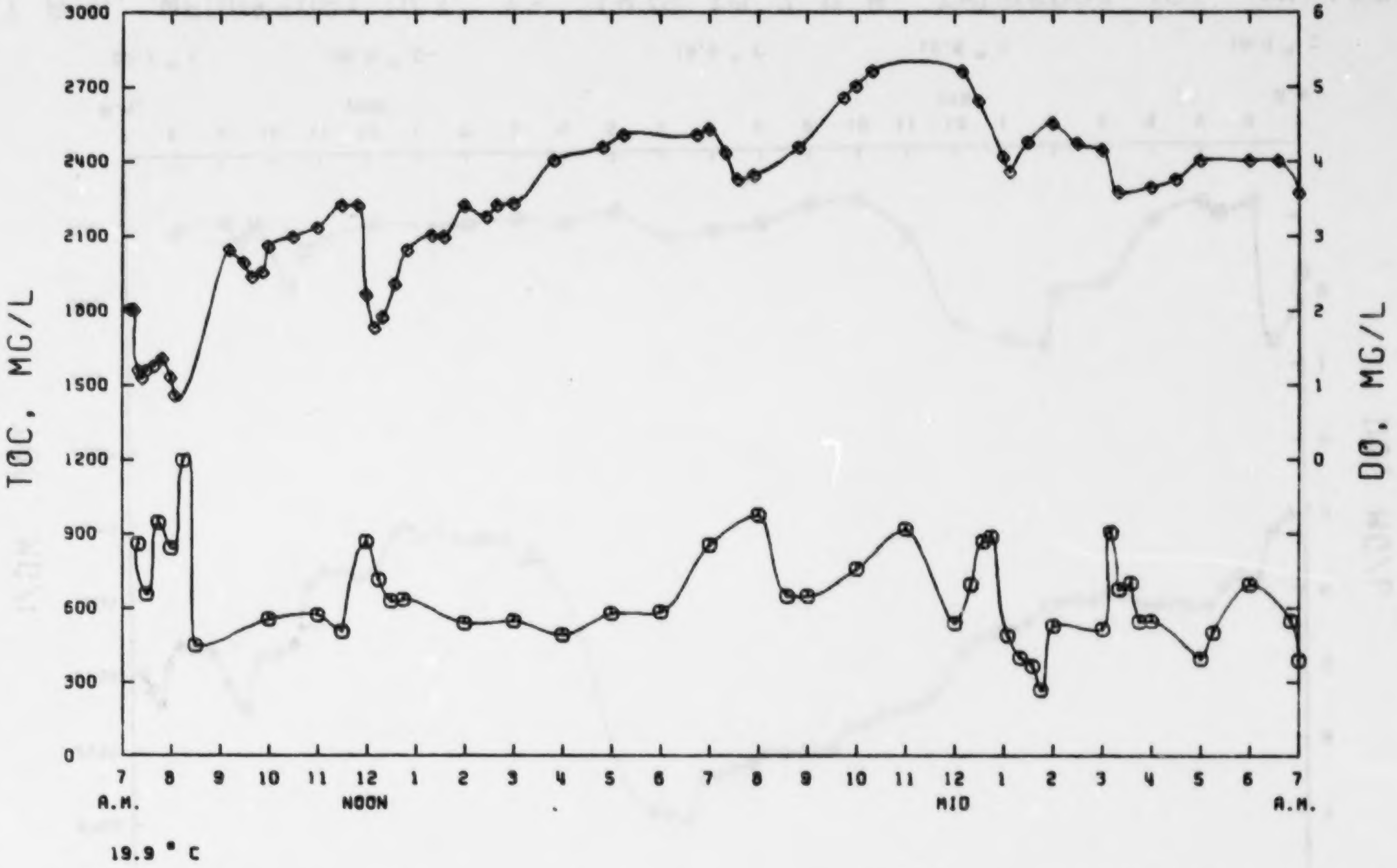
7 A.M. WEDNESDAY OCT. 6, 1976 TO 7 A.M. THURSDAY OCT. 7, 1976



RESULTS FROM BIOMONITOR AT INDUSTRIAL SITE 1

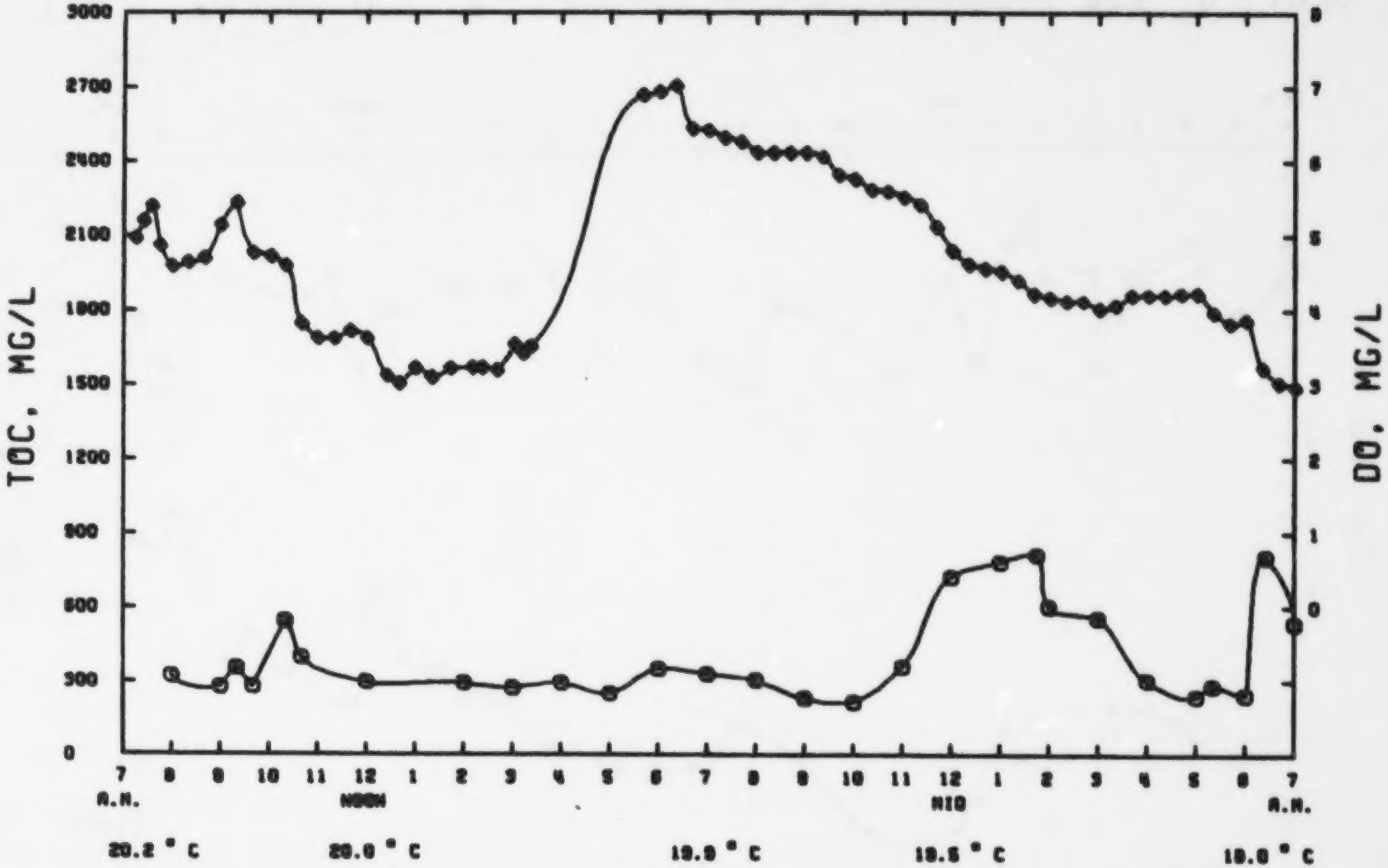
7 A.M. THURSDAY OCT. 7, 1976 TO 7 A.M. FRIDAY OCT. 8, 1976

RESULTS FROM BIOMONITOR AT INDUSTRIAL SITE 1



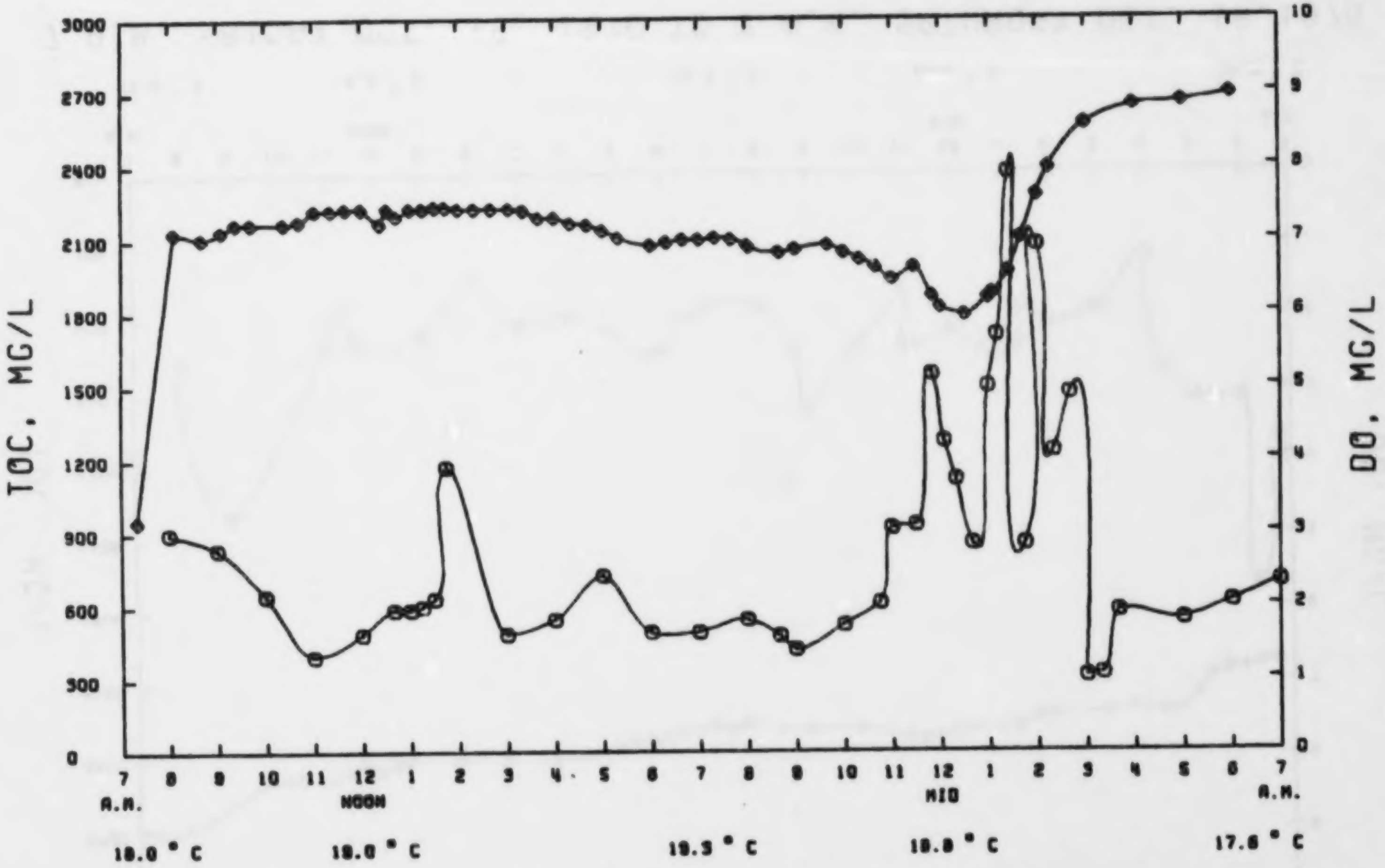
7 A.M. FRIDAY OCT. 8, 1976 TO 7 A.M. SATURDAY OCT. 9, 1976

RESULTS FROM BIOMONITOR AT INDUSTRIAL SITE 1



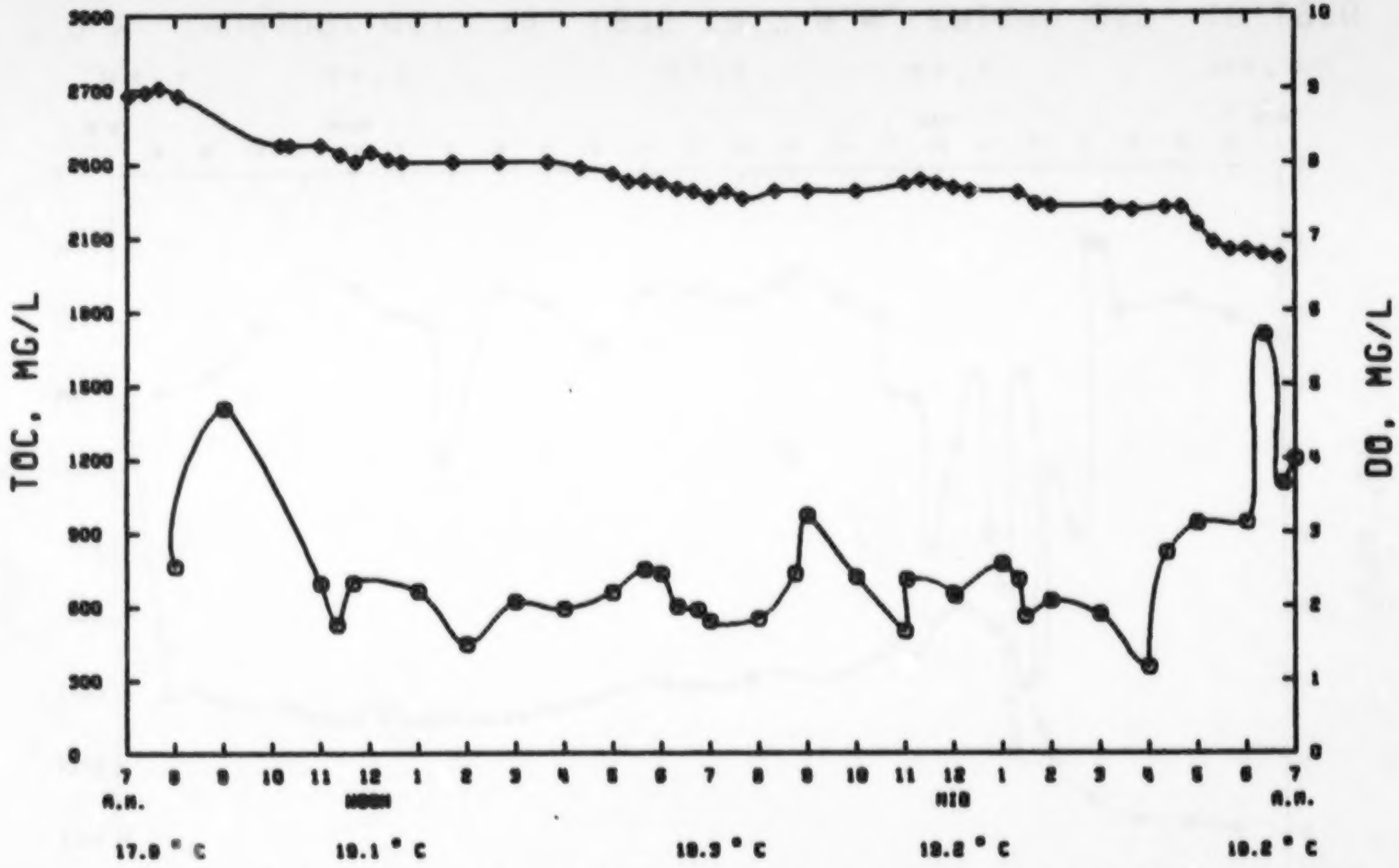
7 A.M. WEDNESDAY OCT. 13, 1976 TO 7 A.M. THURSDAY OCT. 14,1976

RESULTS FROM BIOMONITOR AT INDUSTRIAL SITE 1



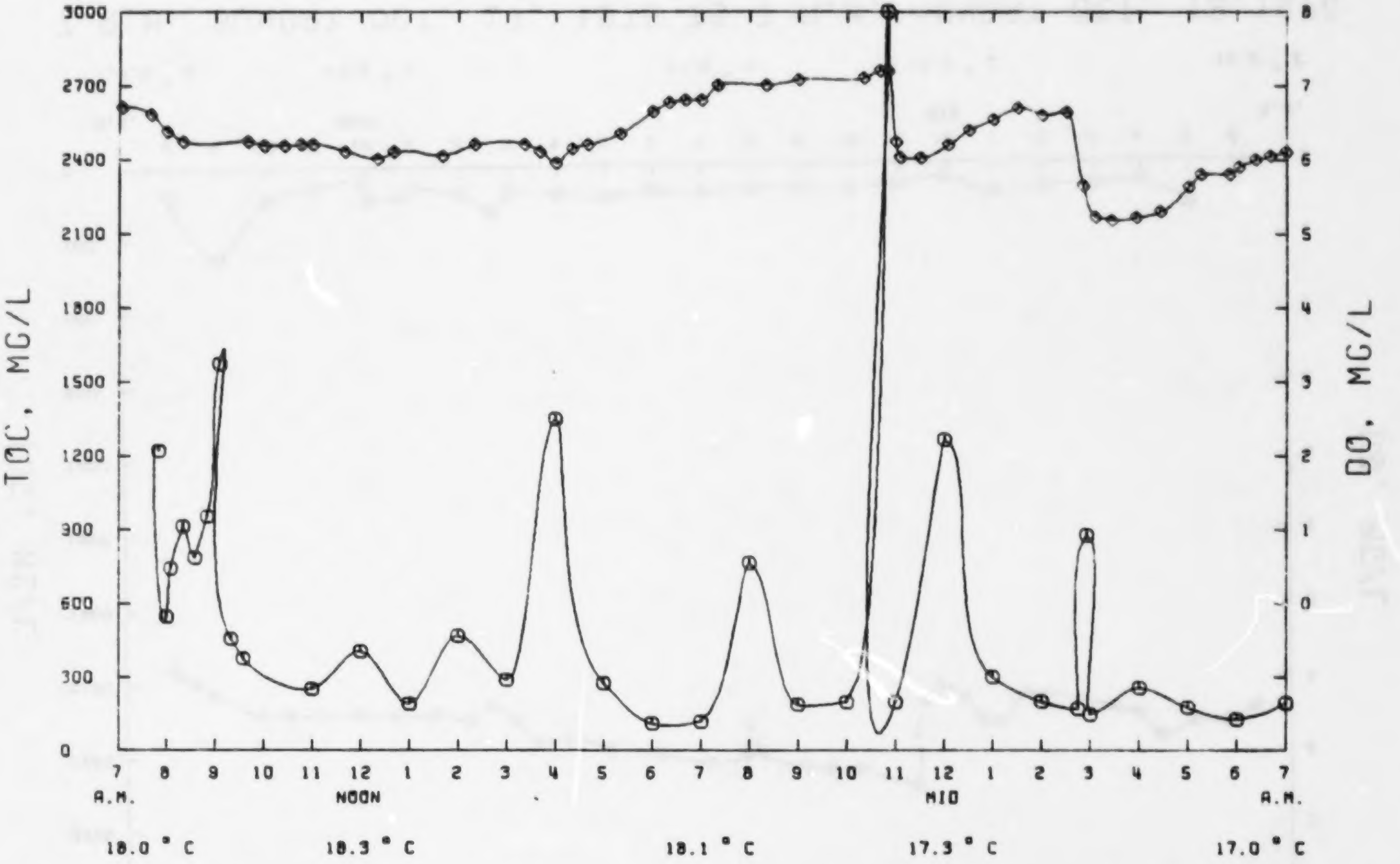
7 A.M. THURSDAY OCT. 14, 1976 TO 7 A.M. FRIDAY OCT. 15,1976

RESULTS FROM BIOMONITOR AT INDUSTRIAL SITE 1



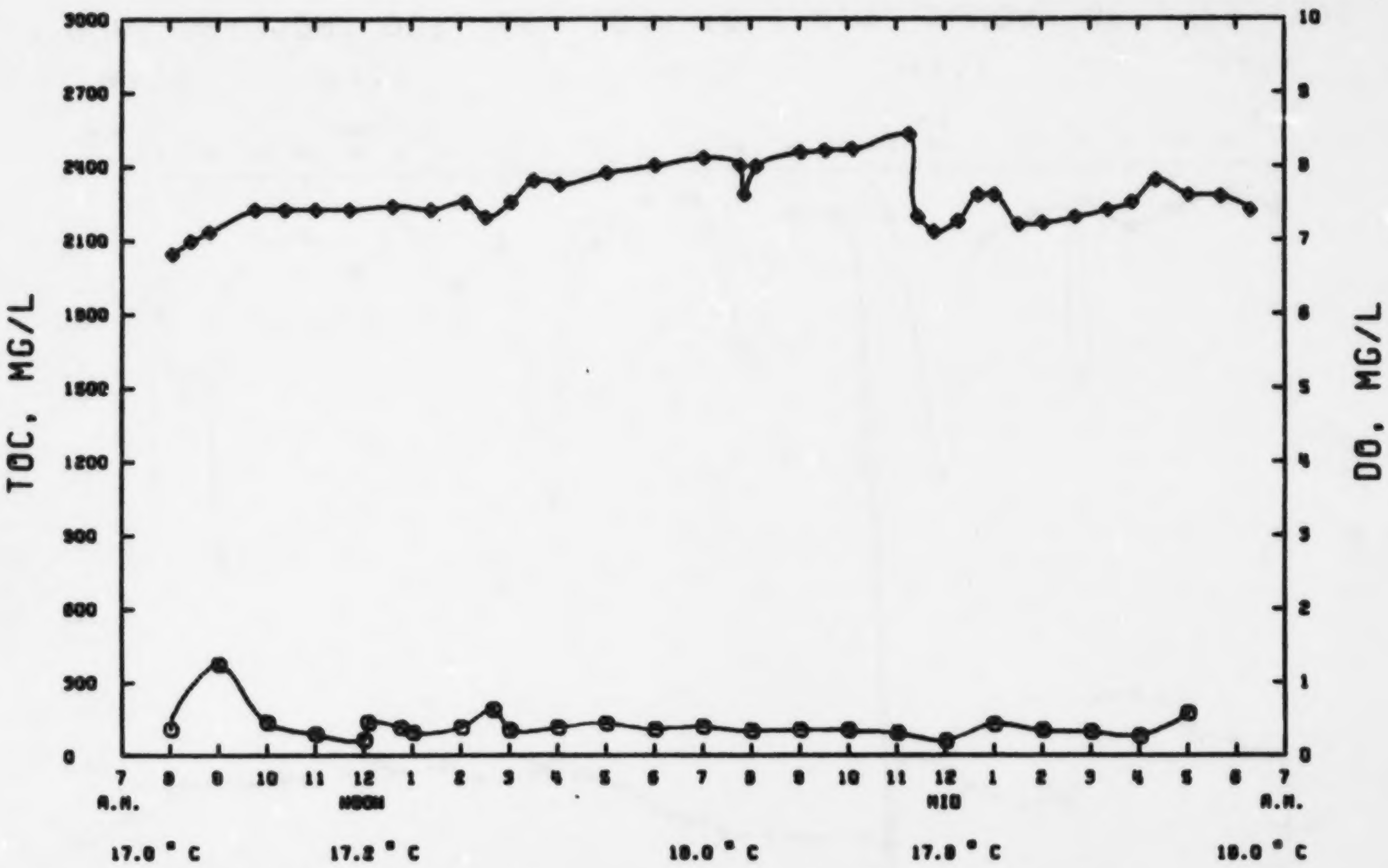
7 A.M. FRIDAY OCT. 15, 1976 TO 7 A.M. SATURDAY OCT. 16,1976

RESULTS FROM BIOMONITOR AT INDUSTRIAL SITE 1



7 A.M. SATURDAY OCT. 16, 1976 TO 7 A.M. SUNDAY OCT. 17, 1976

RESULTS FROM BIOMONITOR AT INDUSTRIAL SITE 1

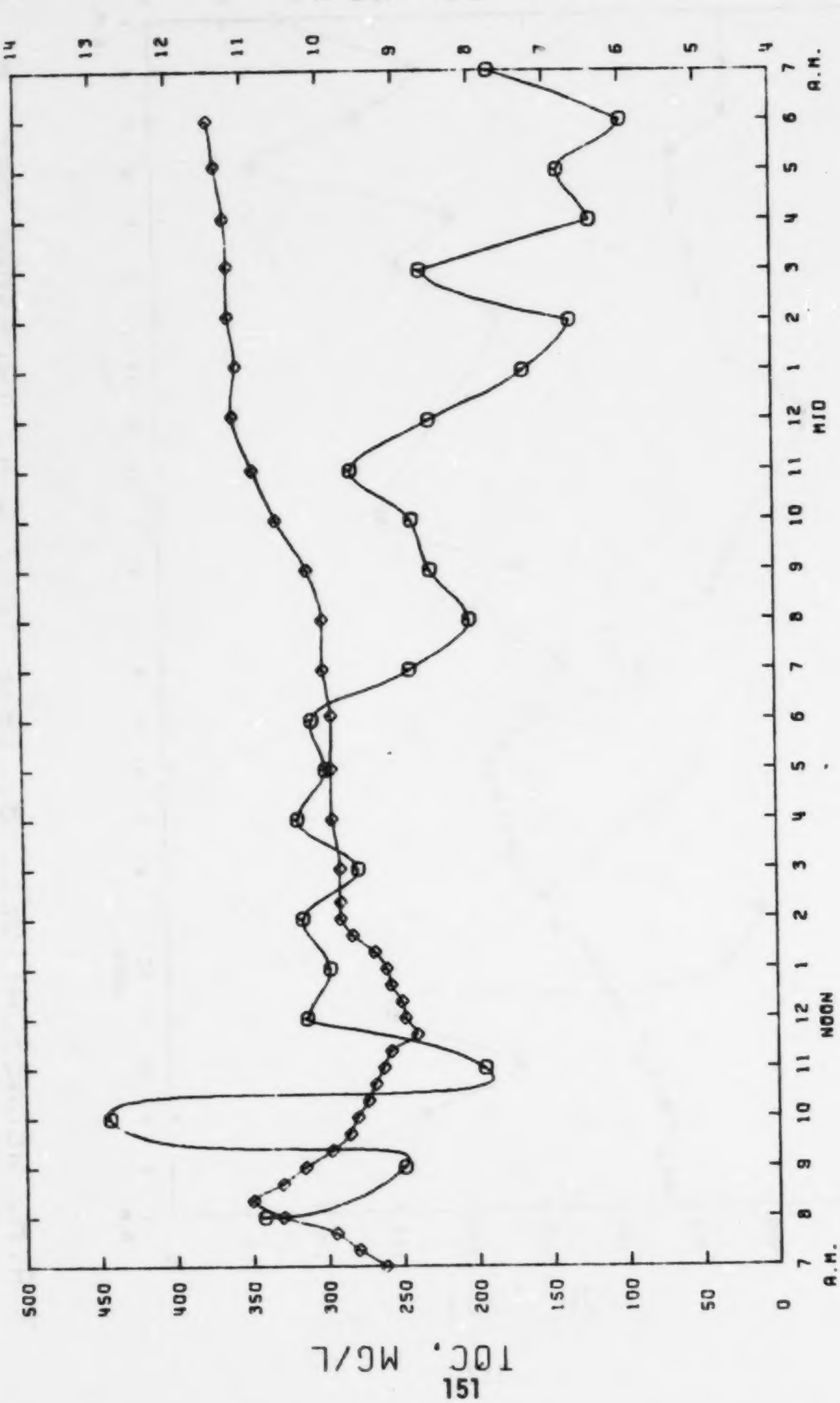


7 A.M. SUNDAY OCT. 17, 1976 TO 7 A.M. MONDAY OCT. 18,1976

APPENDIX F

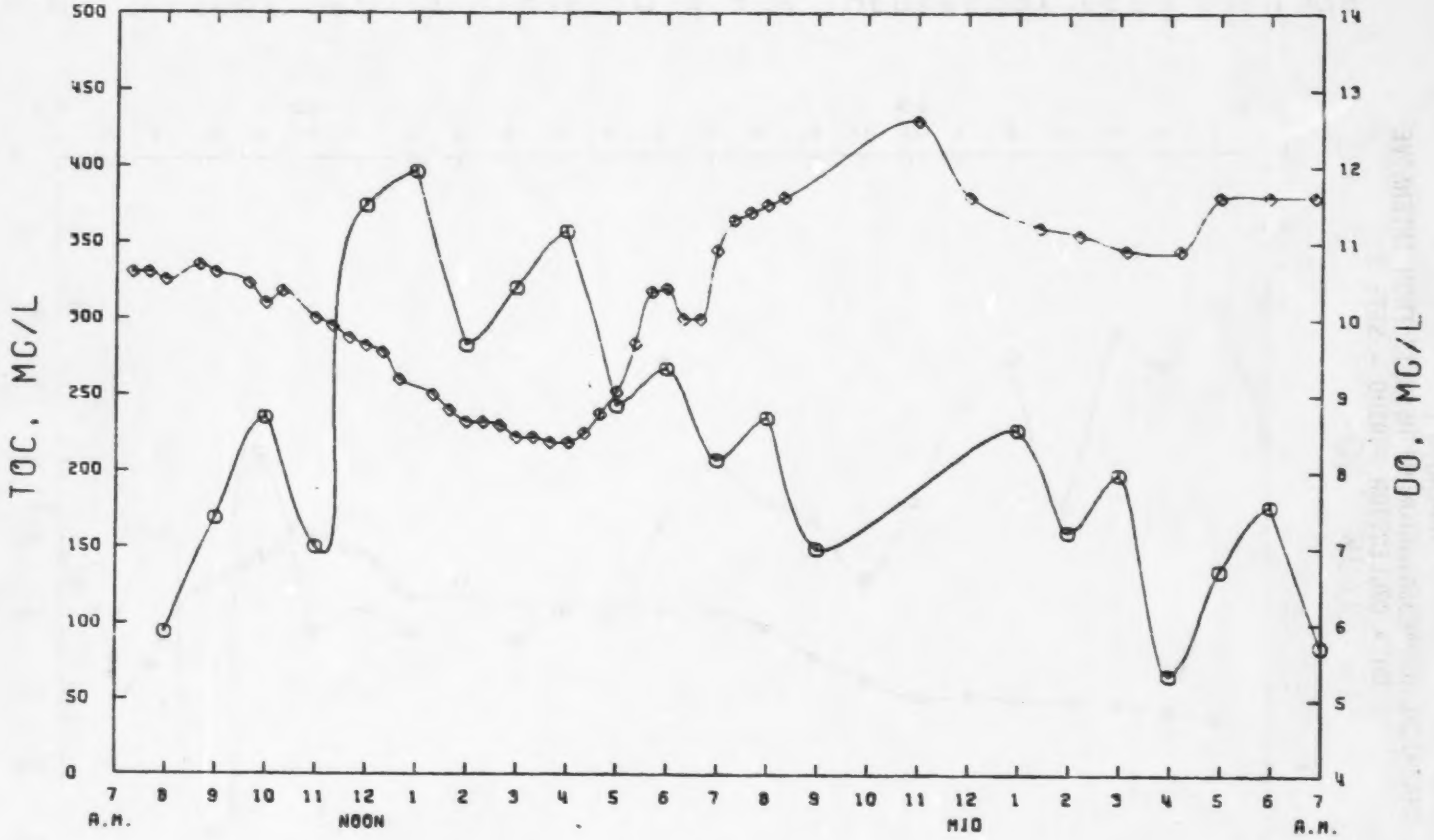
GRAPHICAL REPRESENTATION OF RESULTS FROM INTENSIVE DATA COLLECTION PERIOD - SITE 2

RESULTS FROM BIOMONITOR AT JOINT W.T.P. 2



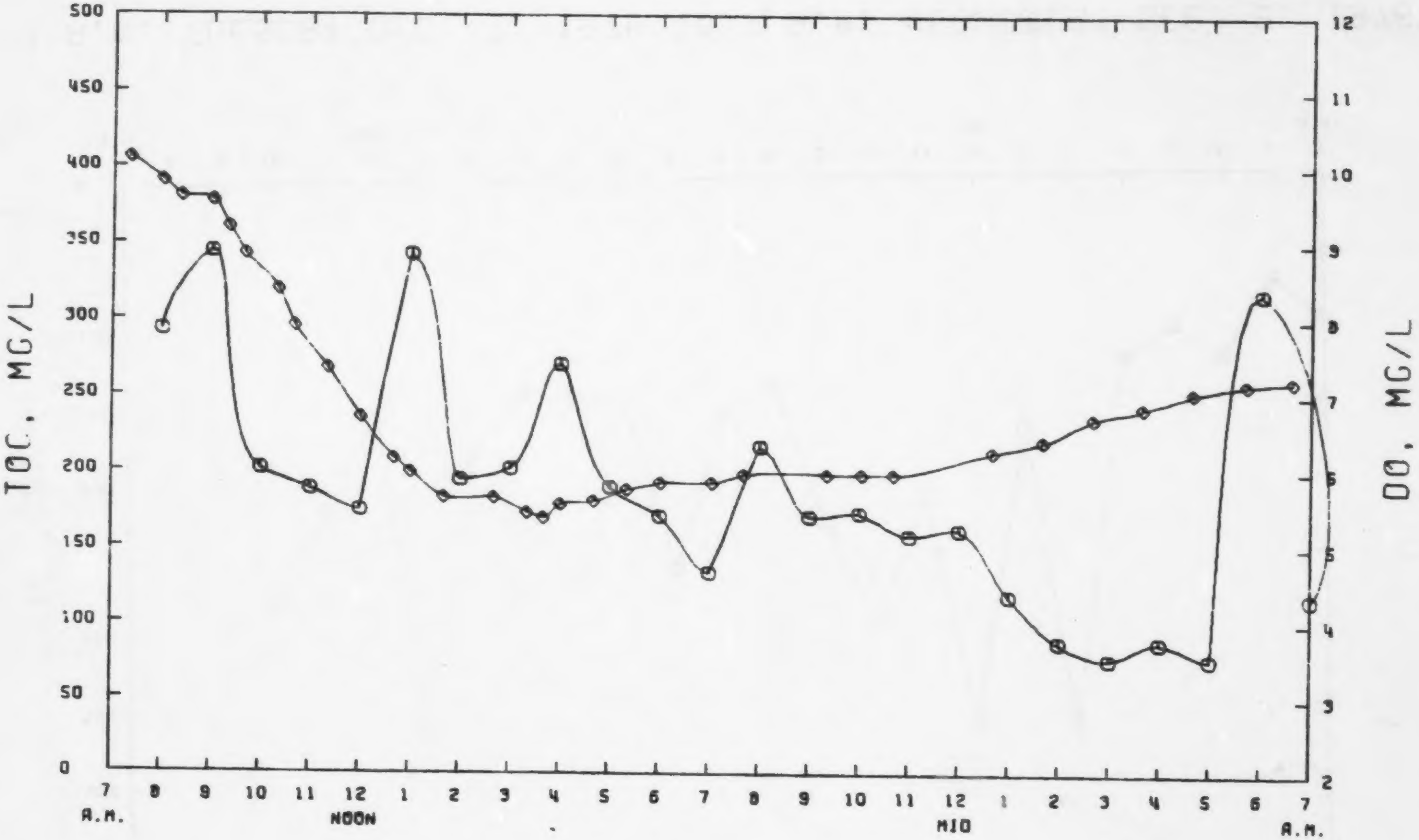
7 A.M. TUESDAY DEC. 7, 1976 TO 7 A.M. WEDNESDAY DEC. 8, 1976

RESULTS FROM BIOMONITOR AT JOINT W.T.P. 2



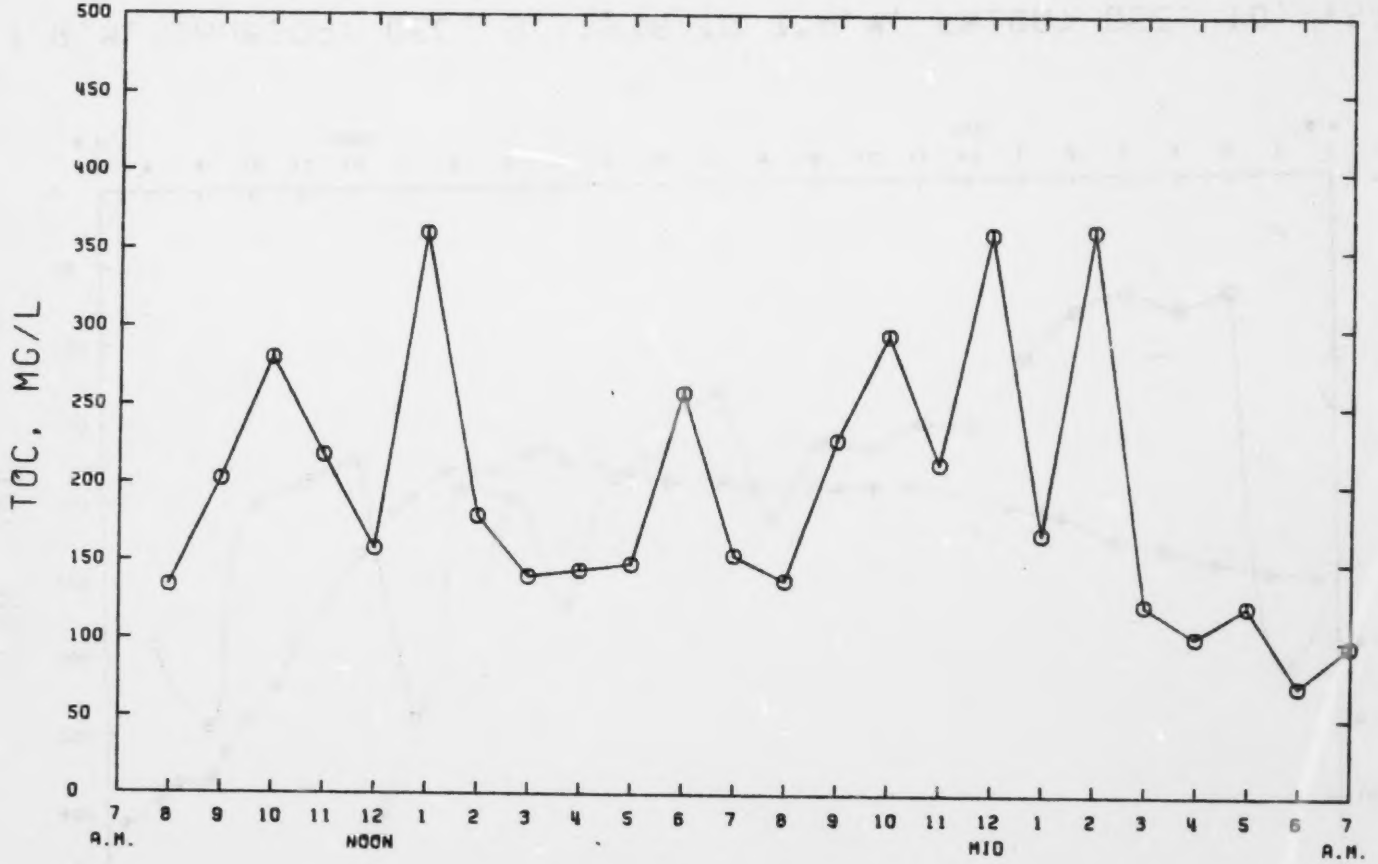
7 A.M. WEDNESDAY DEC. 8, 1976 TO 7 A.M. THURSDAY DEC. 9, 1976

RESULTS FROM BIOMONITOR AT JOINT W.T.P. 2



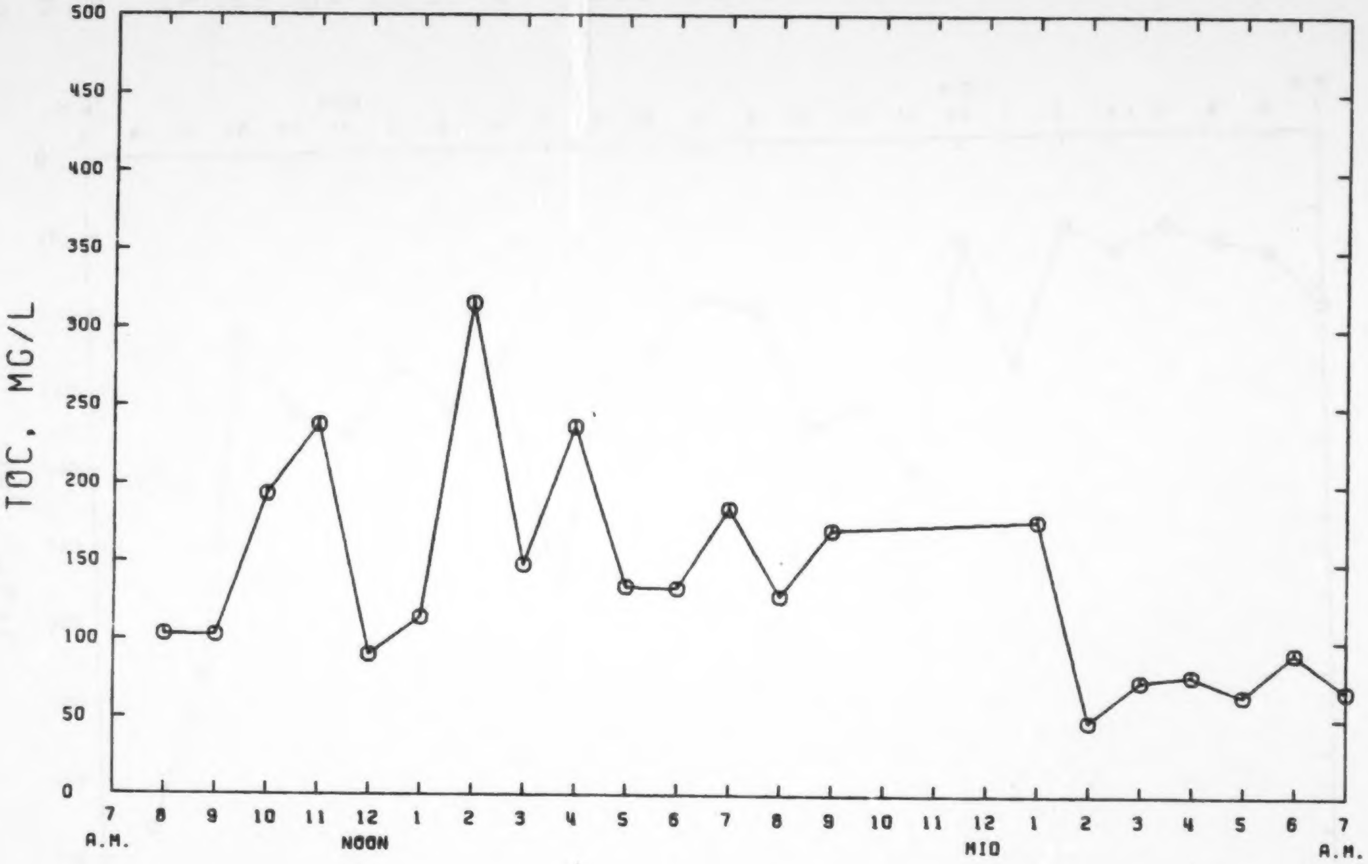
7 A.M. THURSDAY DEC. 9, 1976 TO 7 A.M. FRIDAY DEC. 10, 1976

EFFLUENT CONCENTRATION AT JOINT W.T.P. 2



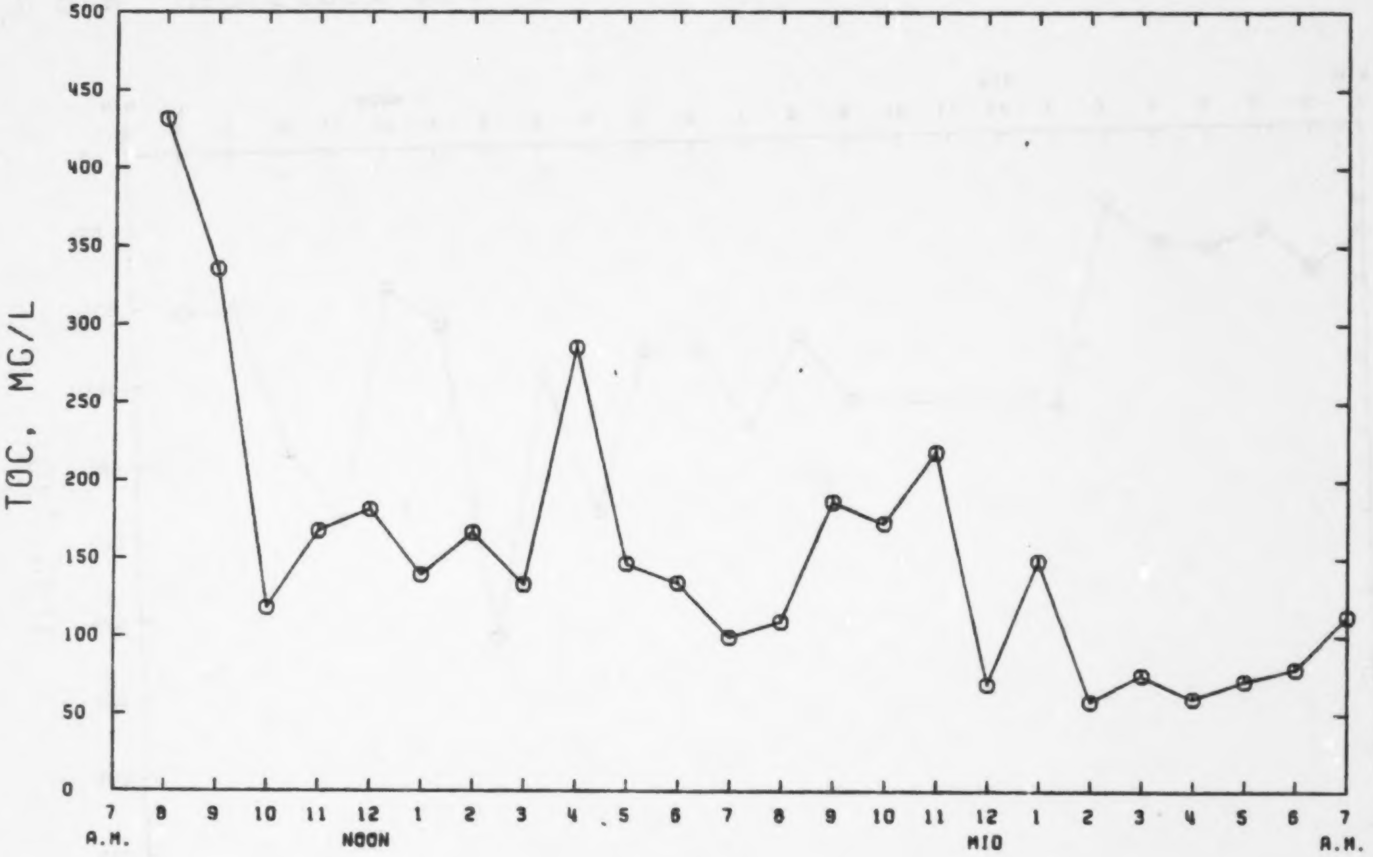
7 A.M. TUESDAY DEC. 7, 1976 TO 7 A.M. WEDNESDAY DEC. 8, 1976

EFFLUENT CONCENTRATION AT JOINT W.T.P. 2



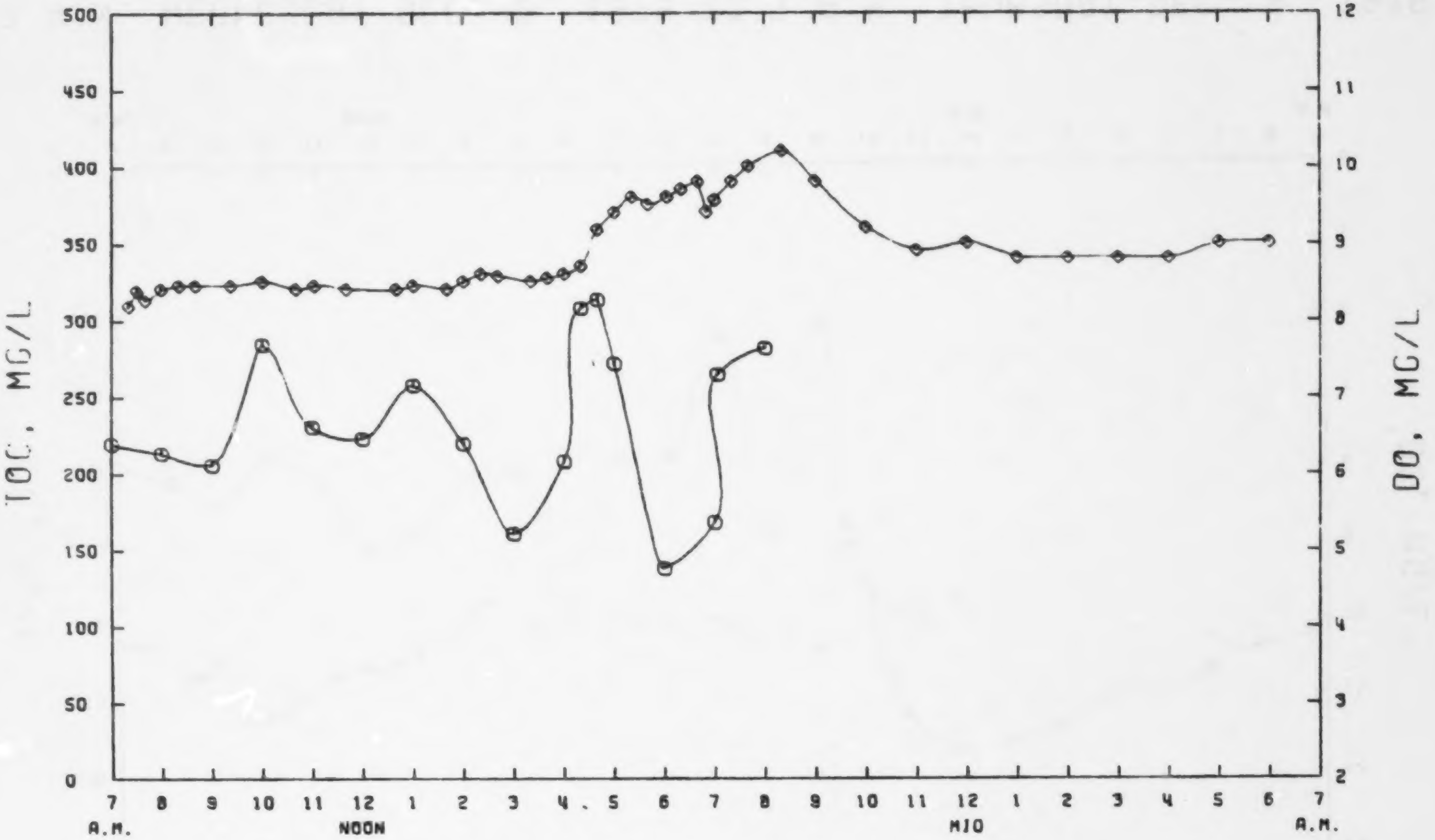
7 A.M. WEDNESDAY DEC. 8, 1976 TO 7 A.M. THURSDAY DEC. 9, 1976

EFFLUENT CONCENTRATION AT JOINT W.T.P. 2



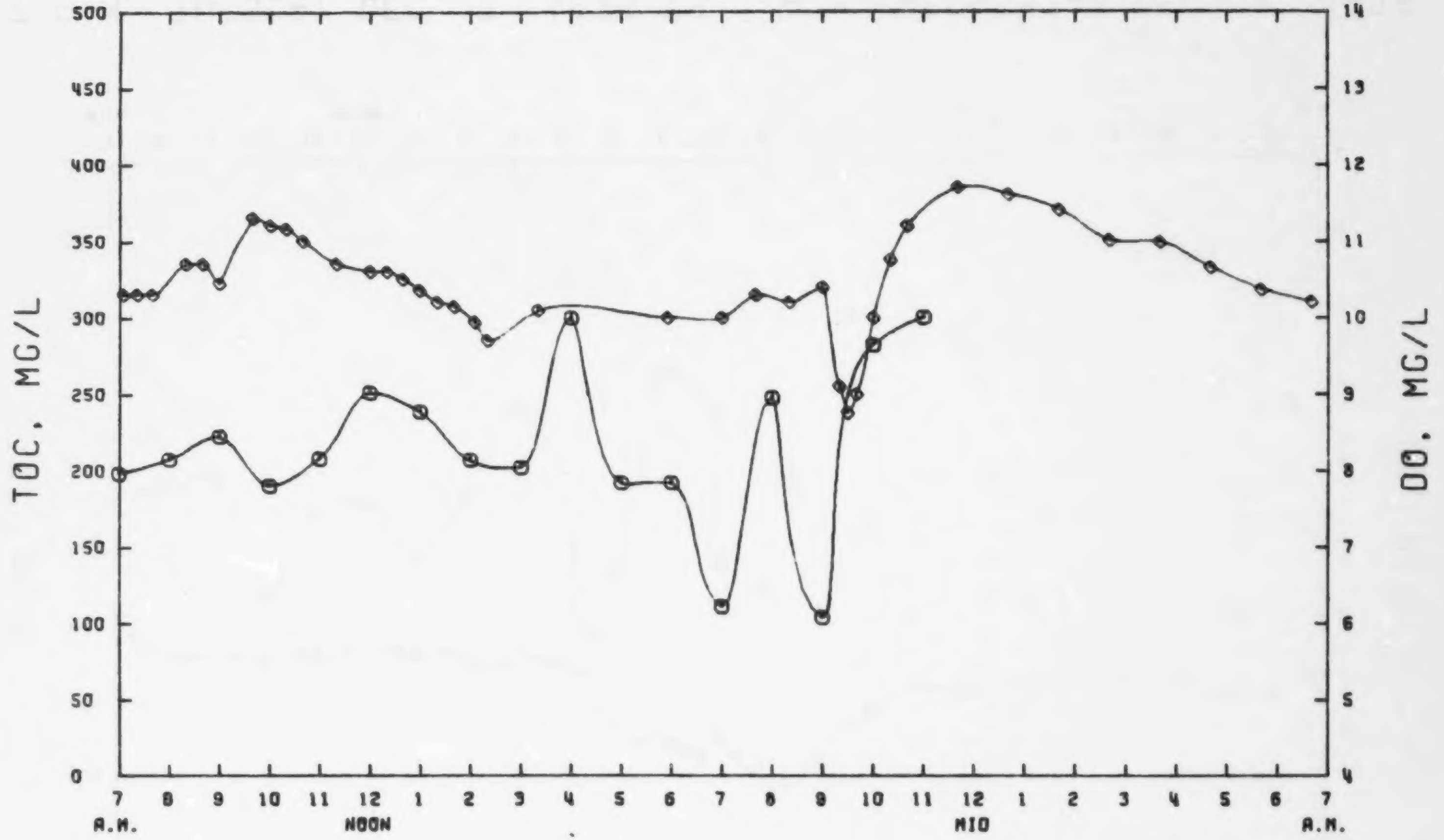
7 A.M. THURSDAY DEC. 9, 1976 TO 7 A.M. FRIDAY DEC. 10, 1976

RESULTS FROM BIOMONITOR AT INDUSTRIAL SITE 2



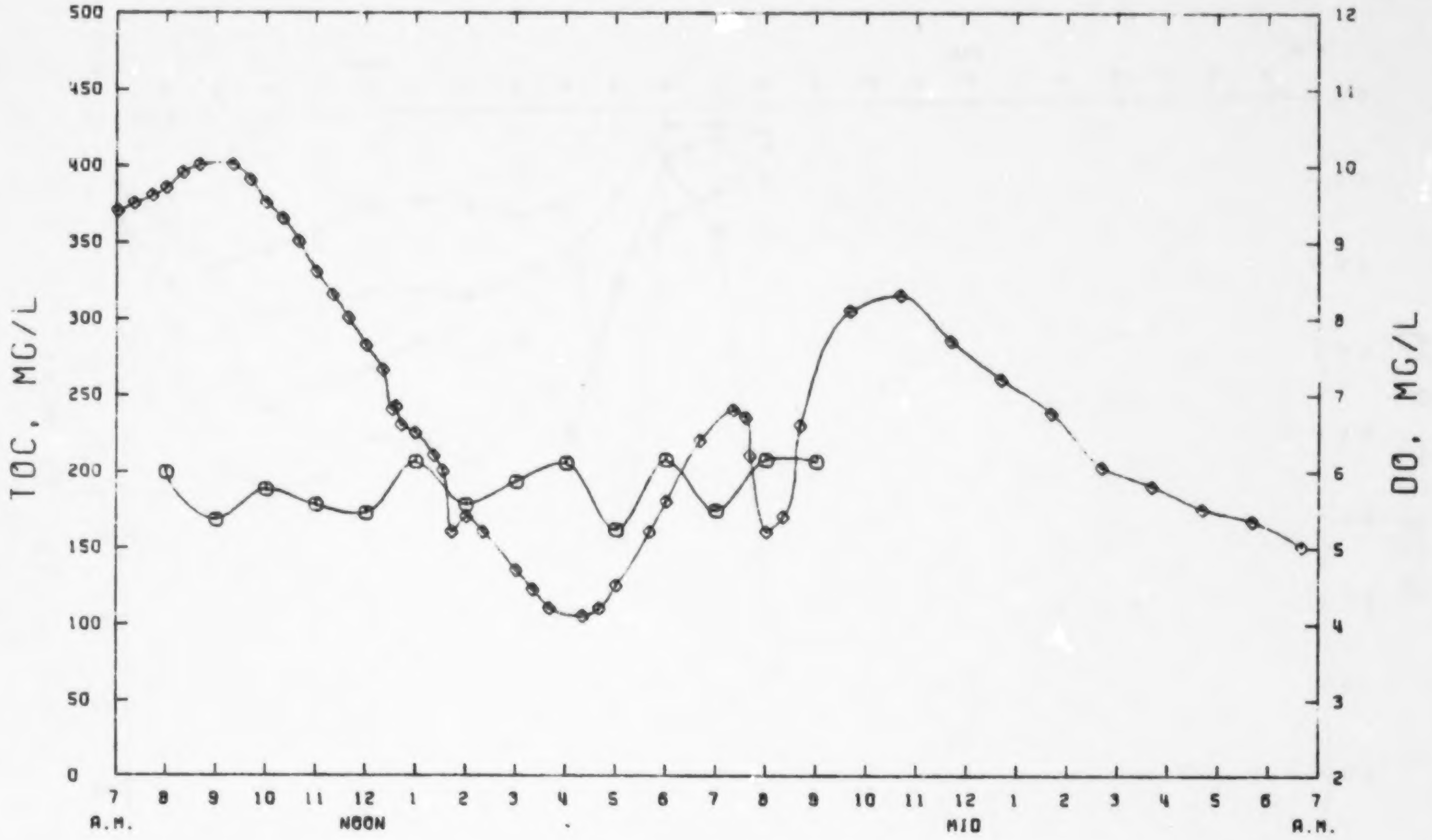
7 A.M. TUESDAY DEC. 7, 1976 TO 7 A.M. WEDNESDAY DEC. 8, 1976

RESULTS FROM BIOMONITOR AT INDUSTRIAL SITE 2



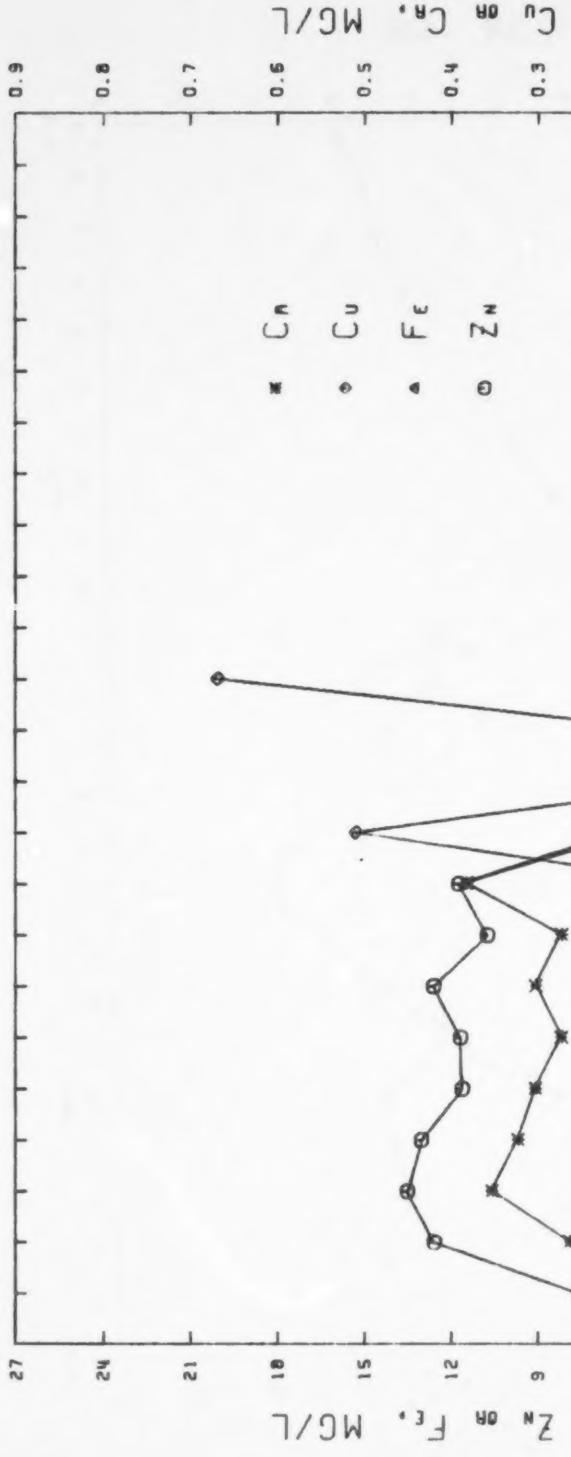
7 A.M. WEDNESDAY DEC. 8, 1976 TO 7 A.M. THURSDAY DEC. 9, 1976

RESULTS FROM BIOMONITOR AT INDUSTRIAL SITE 2



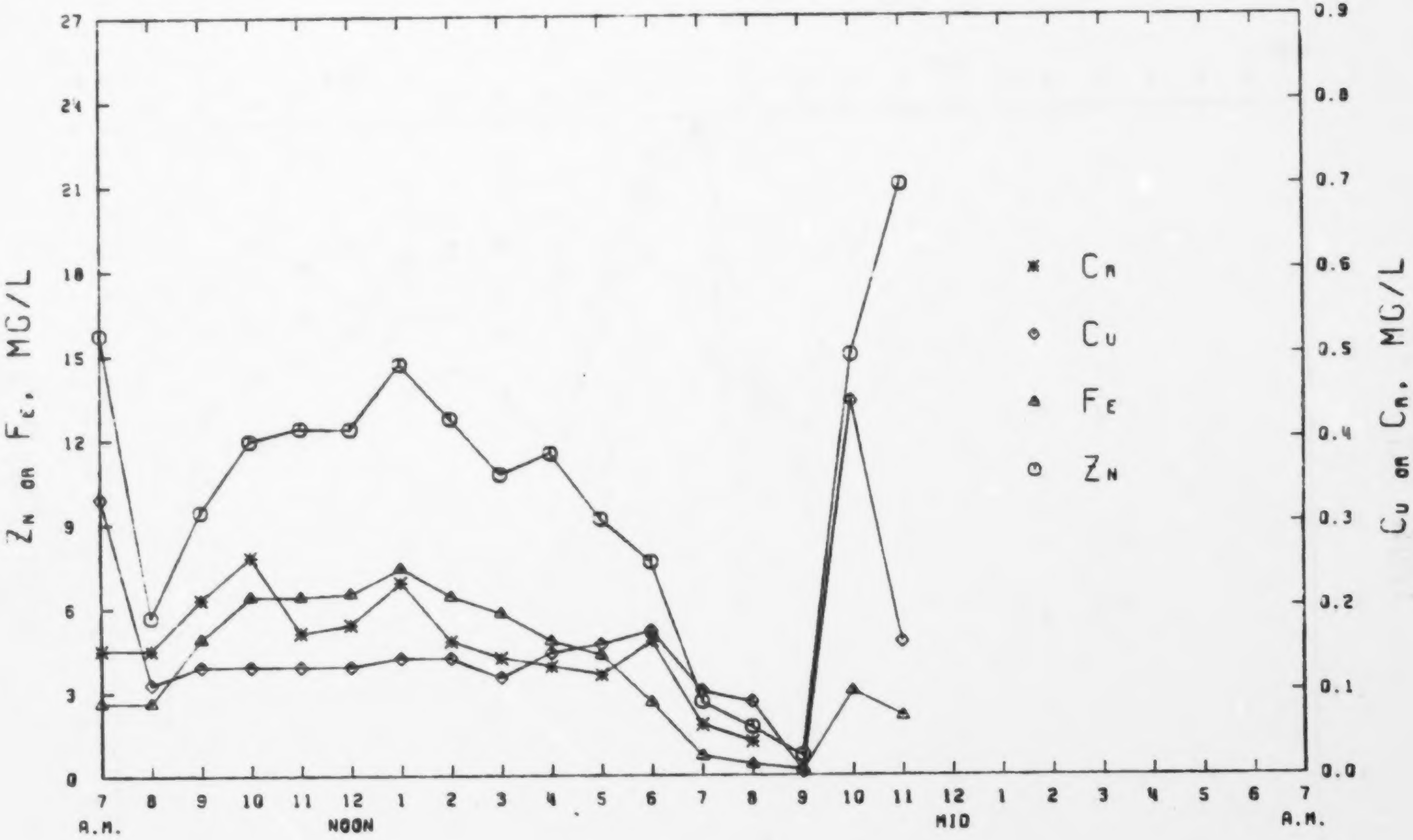
7 A.M. THURSDAY DEC. 9, 1976 TO 7 A.M. FRIDAY DEC. 10, 1976

METAL CONCENTRATION AT INDUSTRIAL SITE 2



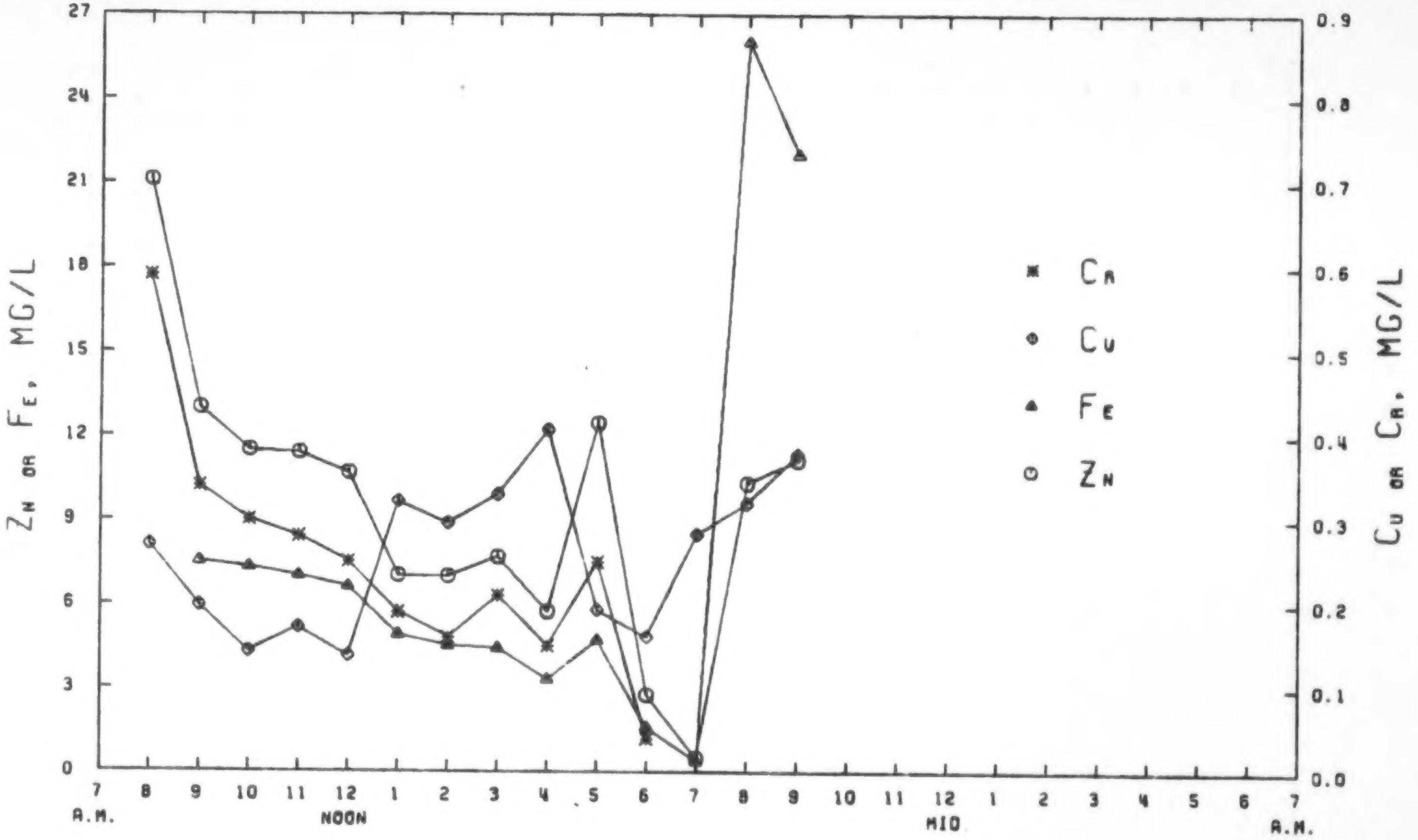
7 A.M. TUESDAY DEC. 7, 1976 TO 7 A.M. WEDNESDAY DEC. 8, 1976

METAL CONCENTRATION AT INDUSTRIAL SITE 2



7 A.M. WEDNESDAY DEC. 8, 1976 TO 7 A.M. THURSDAY DEC. 9, 1976

METAL CONCENTRATION AT INDUSTRIAL SITE 2



7 A.M. THURSDAY DEC. 9, 1976 TO 7 A.M. FRIDAY DEC. 10, 1976